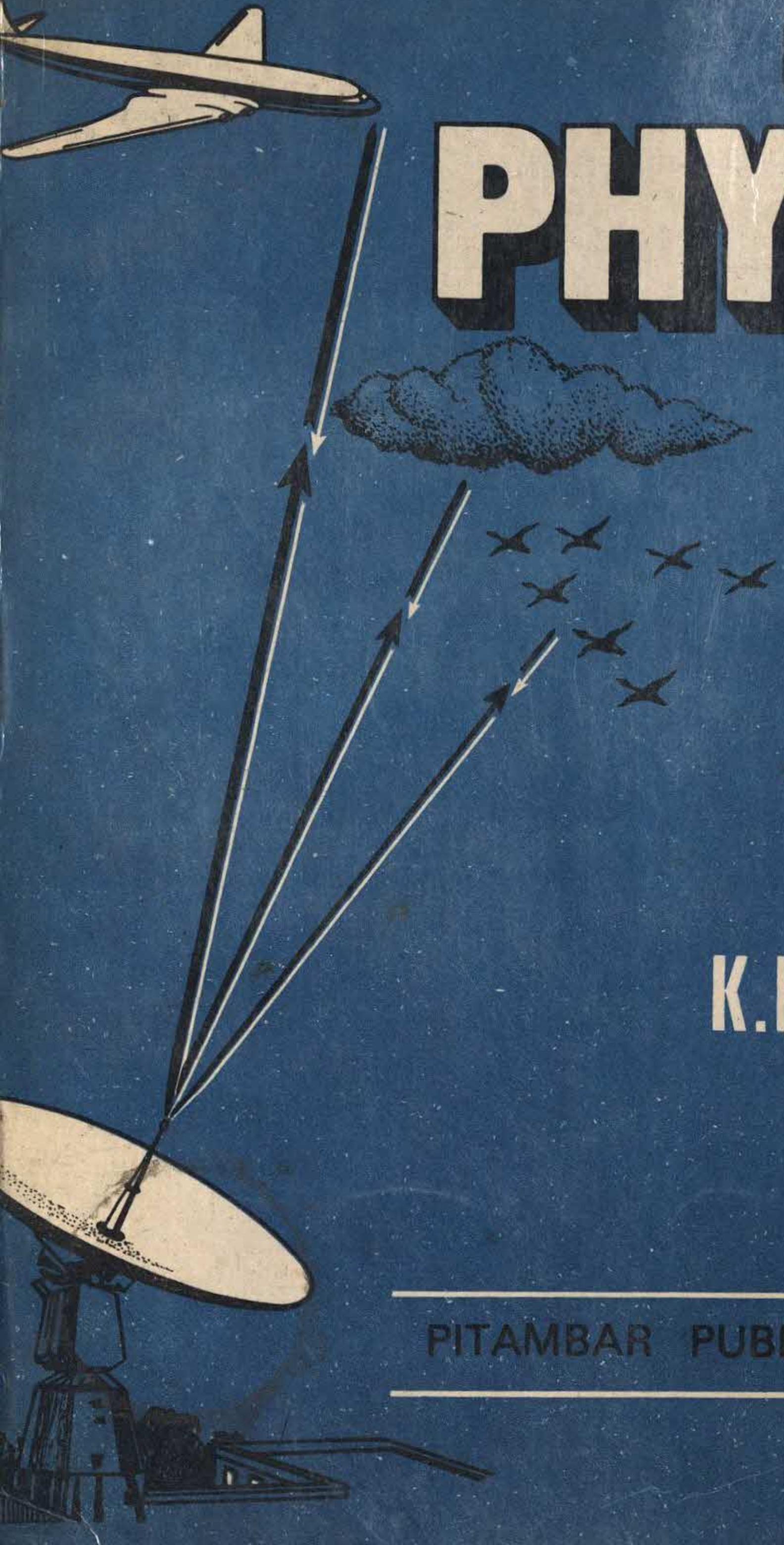
Fundamentals of PHYSICS

VOL. II



K. K. MOHINDROO

PITAMBAR PUBLISHING COMPANY

Strictly according to the latest syllabus prescribed by the Central Board of Secondary Education, New Delhi in Physics for class X of Secondary School Certificate Examination.

FUNDAMENTALS
OF
PHYSICS

VOL. II
[FOR CLASS X]

By

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PREFACE

For the last few years there has been growing an awareness in the country that if our students are to be given useful knowledge of contemporary science, the syllabi need updating. The learning period remaining the same, a fresh approach has to be made to cope with the exponential growth of the subject. The Central Board of Secondary Education, New Delhi has introduced new and advanced course in Physics in the secondary school curriculum which would cultivate scientific temper and scientific thinking. It is with this aim in view that the present book FUNDAMENTALS OF PHYSICS for class X course for the academic stream of the 10+2 pattern of education has been written. The book has been written after a long and direct contact of about 27 years with the students of Physics and in this period of contact, I had the priviledge to come across the actual problems confronting the students. A sincere and strenuous effort has been put in.

The subject matter included in this book is in accordance with the new syllabus. Each chapter in the book is self-contained and comprehensive. The material included in the book is in conformity with the trend of the new scheme *i.e.*, to introduce a more *basic* approach to the study of Physics from the point of view of clarity, comprehension and application.

SI and c.g.s. systems of units have been used throughout. Many solved examples and unsolved problems are given in SI system. The questions at the end of each chapter have been framed which would keep the student's mind always active—an approach which is quite adverse to the traditional one.

The symbols used in the book have been selected mainly in conformity with the recommendations of N.C.E.R.T. and C.B.S.E. Other *special features* of this book are :—

(*i*) Language is simple and lucid.

(*ii*) Diagrams are clear, neat, well-illustrated and accurately drawn.

(*iii*) The style of the book and quality of content is such that it would lead the student to better understanding and he would gain self-confidence, and would *abhor hankering after cheap books which give memory courses only*. The students would be able to *face the examinations with confidence*.

(*iv*) Greater emphasis has been laid on basic concepts

(*v*) The book will increase the students' ability and willingness *to inquire* for themselves.

The aim of the book is, however, not to replace the teacher. The teacher in the classroom can always train a young pupil on proper lines ; the present book is to serve as an aid for this purpose.

I am thankful to several of my colleagues from Public Schools, Central Schools, Government and Aided Schools, friends and students for their valuable suggestions, criticism and help in the preparation of this book. I shall feel greatly obliged to those readers who will bring to my notice the errors and shortcomings of the book and forward to me their suggestions for its improvement.

In the end, I sincerely thank M/s Pitambar Publishing Company for publishing this book in a very short span of time.

K.K. MOHINDROO

NOTE

In order to achieve the main objectives of the Physics course *effectively*, it is important that the classroom teaching be supported by *demonstration experiments*. **Teachers may encourage discussion between students to clarify concepts**. Students may be involved in simple activities and projects for developing *scientific temper* ; *enquiry approach* ; laboratory skills and a proper understanding of the concepts and phenomena relating to everyday life situations.

Practice in solving relevant numerical problems needs to be emphasized.

SYLLABUS PRESCRIBED BY C.B.S.E., NEW DELHI

Physics—Class X

Paper I : Theory
Time : 1½ Hrs.

Marks : *50*

Unitwise Distribution of Marks

Unit	*Topic*	*Marks*
I	Our Journey Round the Sun	3
II	States of Matter	9
III	Waves & Sound	8
IV	Light	12
V	Electricity & Magnetism	13
VI	Atomic Structure of Matter	5

I OUR JOURNEY ROUND THE SUN

Periods : *5*

This unit deals with a brief account of the structure of the solar system. As such it is related to Unit I of class IX where a general description of the night sky (the stars, constellations and planets) was given. The rotatory motion of the earth about its axis and around the sun is discussed in detail. The contents of this unit would thus help students to understand and appreciate various natural phenomena like length of the day and change of seasons.

Content

The sun, brief description of the planets, motions of the Earth, change of seasons, sign of the zodiac.

II STATES OF MATTER

Periods : *15*

The major objective of this unit is to enable students to distinguish between various properties of solids, liquids and gases on the basis of their structure and molecular forces existing between the particles.

The concept of elasticity, phenomenon of surface tension, Archimede's principle and Bernoulli's principle has been discussed and explained by taking interesting axamples from daily life.

Content

Solids : Elastic properties

Fluids : Liquid surface as a stretched membrane, capillary action, Archimede's principle, liquid and air pressure, flow of fluids, statement of Bernoulli's principle and its simple applications.

III WAVES AND SOUND

Periods : *11*

Students are quite familiar with waves formed in strings and on water surface. Common properties of these waves lead to understanding of the properties of sound and electromagnetic waves. Vibrations of the oscillating particles can be considered, as it helps to clear the properties of mechanical waves which generate sound in a medium. This unit is also aimed at developing the concept that wave motion is a process of transference of energy and momentum from point to point in a medium.

The qualitative idea of the principle of superposition of waves leading to the formation of standing waves in string and phenomenon of interference, polarisation and diffraction are also dealt with.

Content

Waves : The ripple tank, water waves, other example of wave motion, transverse and longitudinal waves, periodic waves : amplitude, wave length, frequency, time period, superposition of waves, interference, reflection, standing waves, polarisation, diffraction and refraction.

Sound : Speed of sound, some sources of sound, characteristics of a sound wave—intensity, pitch and quality, ear as an instrument of hearing, resonance—air columns.

IV LIGHT

Periods : *16*

In lower classes students have studied about reflection of light and some applications of this phenomenon. In this unit stress is laid on the laws of reflection and refraction as on the basis of these laws all geometrical optics can be developed. Ideas of ray and image formation have been given.

Characteristic features of spherical mirrors and lenses have been developed. The relationship between object distance, image distance and focal length has been established by using simple geometrical properties. The change in the direction of light rays from one transparent medium to another *i.e.*, through a glass slab, prism and lenses, together with the phenomenon of total internal reflection with its application in mirage, fibre optics have also been discussed.

Some practical uses of mirrors/lenses in making of optical instruments like microscopes, telescopes and spectacles for correcting the defects of vision have been included to bring out their importance in daily life.

Content

Reflection of Light : Reflection at plane surfaces, spherical mirrors, their focal length : graphical method for locating image of an object, sign convention, derivation and use of mirror formula $\frac{1}{v}+\frac{1}{u}=\frac{1}{f}$, magnification and uses of spherical mirrors.

Refraction of Light : Laws of refraction, total internal reflection-its applications-mirage, apparent depth of a transparent medium, light pipe and fiber optics, spherical lenses, its power, image formation by convex lenses and use of lens formula $\frac{1}{v}-\frac{1}{u}=\frac{1}{f}$, lateral magnification.

The Eye-defects of vision—their remedy ; Magnifying glass—its magnifying power ; compound microscope, astronomical telescope (magnifying power not to be derived for any of these) ; dispersion of light by a prism, light as a wave.

V. ELECTRICITY AND MAGNETISM

Periods : *20*

The practical applications of electricity are numerous and well known. The objective of this unit is to introduce students to the study of static and current electricity in such a way that various phenomenon observed in daily life and concerned with this aspect of nature can be understood.

The concepts of charge, field intensity and potential have been introduced in static electricity. The current as a flow of charges, resistance and potential difference are the three basic concepts which have been dealt within current electricity. The sources of current—its various effects, simple circuits and their practical applications have been discussed. Magnetic effect of current and its applications to galvanometer, motor etc. are also discussed. Importance of earth's magnetic field has been highlighted in the form of elements of earth's magnetic field.

Content

Electricity : Electric charge ; conductors and insulators : electric induction ; Coulomb's law of force between charges ; principle of superposition, electric field, electric lines of force ; potential difference. Electric current and its unit, resistance. Ohm's law, resistances in series and parallel, resistivity, heating effect of electric current, electric power and watt, electric energy kilowatt hour. Chemical effect of current, electrolysis and its applications.

Magnetism and Electromagnetism Properties of bar magnets, magnetic field and lines of force, magnetic field around a straight conductor, field due to a circular coil and a solenoid, force on a current carrying conductor placed in a magnetic field, interaction between two current carrying wires, unit of current, galvanometer, ammeter and voltmeter-construction and working (qualitative treatment only). Use of galvanometer as an ammeter and a voltmeter.

Electromagnetic induction, electric generator, simple idea of transformer, household electric circuits and fuse.

Elements of earth's magnetic field.

VI ATOMIC STRUCTURE OF MATTER *Periods* : 7

Atomic energy has become a household name in the modern world. As all human progress including economic development depends on the use of this energy. It is thus very important for the child to know about the structure of atoms. Radioactive elements have various useful applications as well as harmful effects and so it is the right time to give the idea of radioactive substances.

Content

Granular structure of matter, atomic motion, structure of atoms. Isotopes, radioactivity, nuclear reactions, fission and fusion, uses of radiations and radioisotopes.

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CHAPTER 1

Our Journey Round the Sun

1.1. INTRODUCTION

A casual glance at the night sky reveals a variety of interesting objects. In class IX, you have learnt how to identify some of the celestial objects visible at night to the naked eye. They appear to move across the sky from east to west. The apparent motion arises because of the rotation of the earth about its axis. The earth on which we live is simply one of a family of planets revolving around the sun, while the sun itself is no more than one very ordinary star in the huge stellar system—the Milky Way—which is our galaxy. Likewise, our galaxy is merely one minute speck among the vast hordes of galaxies which stretch to the edge of the observable universe—some of them so far distant that their light takes thousands of millions of years to reach us. (Light travels with a speed of 3×10^8 m/s). Against the background of the universe, the Earth seems very insignificant indeed. How much more insignificant is man !

The sun, its planets, their moons ; comets and various smaller pieces of orbiting rock, make up the **solar system** In recent years the family has been increased by hundreds of artificial earth satellites. The sun is so vast—750 times as big as all the rest of the matter in the solar system put together—it is able, by its great gravitational pull, to hold all this matter spinning round it.

In this chapter, we will learn more about the sun, the planets, motions of the earth ; change of seasons and sign of the zodiac *i.e.*, changes that appear in the night sky as we journey round the sun.

1.2. THE SUN

The sun is only a very ordinary star, but to our earth, and everyone on it, it is all-important. This fiery ball of hot gas breathed life into our planet, giving us warmth and light. Without it the earth would be a cold, airless and lifeless ball of rock wandering in space.

Our sun is not a particularly big star. It seems large because it is very much closer to earth than any other. Its distance from the earth is about 150 million km (which is called the **astronomical unit**), so close by astronomical standards, its light reaches earth in only 8 minutes. Light from the next nearest star, Alpha Centauri, takes over 4 years to reach us. Distances between us and the stars are so great that they are measured in light-years. A light-year is the distance that a beam of light travels in a year—and light travels at the almost unbelievable speed of 300000 km/s. Nothing travels faster than light.

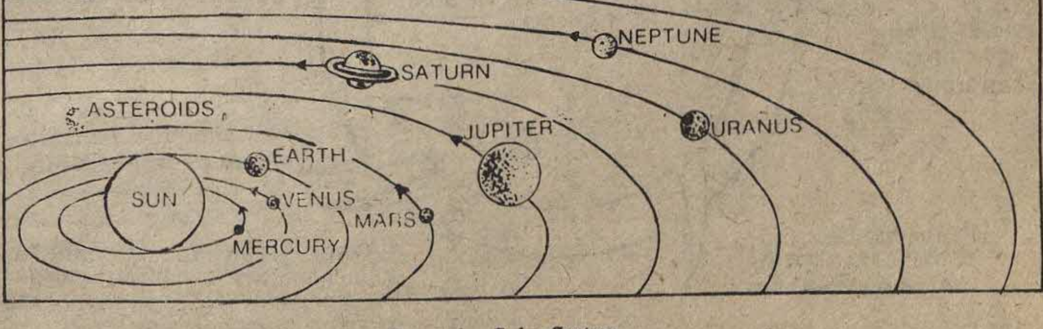


Fig. 1.1. Solar System

Like other stars, the sun is made of hydrogen and helium. At the very great temperature and pressure in its interior—14 million degree celcius and 400000 million times atmospheric pressure on earth—hydrogen changes into helium, giving out colossal energy. This process is called **thermo-nuclear fusion.** The sun possesses a huge amount of hydrogen fuel. It has been burning for 5000 million years and will continue to burn for as long again.

The mass of the sun is nearly 2×10^{30} kg and its radius is 7×10^{8} m. It is huge compared to the earth, its diameter being 109 times that of the earth and its mass 333000 times the earth's mass. Its volume is approximately 1 million times the volume of the earth. From its volume and mass one can compute the density, which is 1400 kg m^{-3}, about ¼th the density of the earth.

The surface of the sun that we see from earth is called the **photosphere,** and it is a thin layer only 100 km thick that gives out light and heat rays. Its temperature is 6000 K—at this temperature every material we know will melt and vaporise. Beneath is a zone where hot gases churn up from the interior, producing a patchwork of granules across the surface, each as big as the earth.

Above the surface is the **chromosphere,** the sun's inner atmosphere, and the **corona,** the outer atmosphere; these cannot usually be seen from earth. However, when the surface is hidden during a solar eclipse, the sun's atmosphere can be seen surrounding it like a halo of light.

The sun's surface is always active. Often **sunspots** occur, large regions that appear like dark holes. They look dark because they are not quite so bright as the rest of the surface, but even so they are very hot. Often **solar flares** occur with sunspots, spouting out radiation and particles into space which cause magnetic storms that interfere with radio communications on earth. Arches of light called **prominences** briefly form as streams of bright gas erupt from the surface up into the corona. Hot gases shoot out by as much as half a million kilometres into the solar atmosphere.

The sun is the main source of energy for all members of the solar system. It radiates energy of nearly 10^{26} joule per second in all directions. The earth receives only a small fraction (about 0·00005%) of this energy. On its way to the earth some energy is scattered by air, clouds, dust particles etc., in the sun's

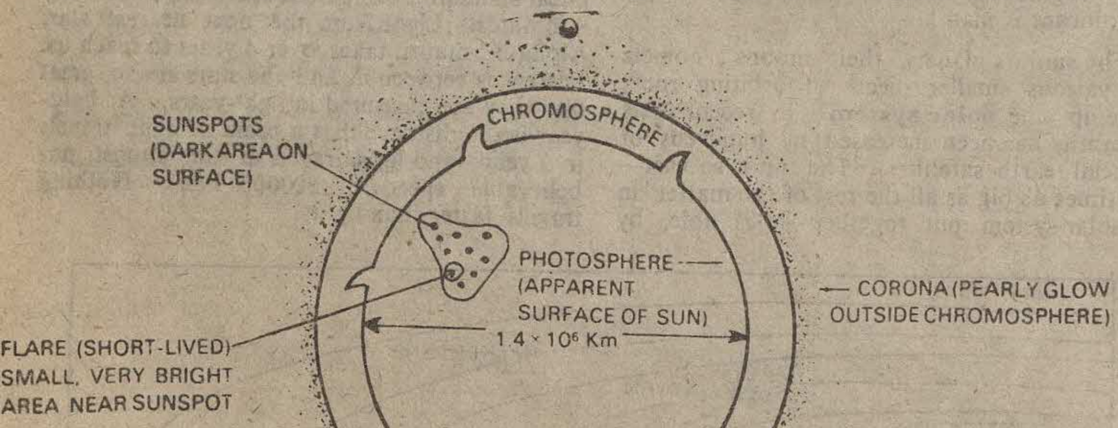

CHROMOSPHERE
SUNSPOTS (DARK AREA ON SURFACE)
PHOTOSPHERE (APPARENT SURFACE OF SUN)
1.4×10^{6} Km
CORONA (PEARLY GLOW OUTSIDE CHROMOSPHERE)
FLARE (SHORT-LIVED) SMALL, VERY BRIGHT AREA NEAR SUNSPOT
PROMINENCES (SCARLET CLOUDS OF MATERIAL NEAR LIMB)
GRANULES (CONTINUALLY CHANGING SMALL BRIGHT AREAS ALL OVER PHOTOSPHERE, GIVING IT A MOTTLED APPEARANCE)

Fig. 1.2. Layers and features of the sun

atmosphere. On the top of the atmosphere, the earth receives energy equal to 1.39×10^3 watt/metre^2 known as **solar constant.** Of this nearly one-third is reflected back into space by the atmosphere of the earth. Planets and other objects in the solar system also reflect part of the sunlight falling on them. This makes them visible to us.

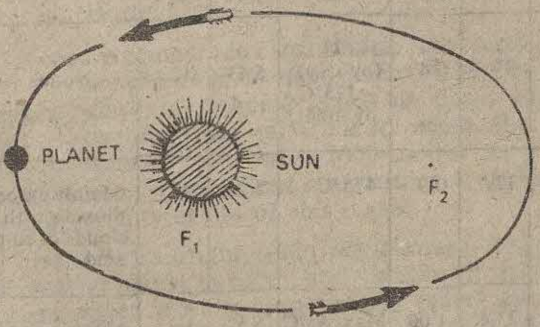


Fig. 1.3. An elliptical orbit with its foci F_1 and F_2.

The planets and other members of the solar system move around the sun in oval paths called **orbits.** These orbits are mostly elliptical (Fig. 1.3). One of the two foci of these orbits coincides with the position of the sun. Surprisingly, the sun is not at the centre of the solar system.

The sun is thought to have formed from a huge cloud of gas and dust, of which there are many in our galaxy. Slowly the gas cloud contracted, and as it did so it began to get hotter and to spin. Eventually the pressure and temperature in the centre became sufficient for nuclear reactions to begin, and the sun rapidly attained its present temperature and settled down to a stable state. Ultimately, though, the sun will use up all its nuclear fuel. It will then collapse and explode—but this need not concern us much, as it will take place at the earliest in five thousand million years' time.

1.3. THE PLANETS

The nine planets of the solar system are very different from one another, as the following brief descriptions and table 1.1 show. The **period of rotation** is the time it takes the planet to turn once itself ; it is the length of the planet's day. The **period of revolution** (or orbital period) is the planet's year—the time it takes to go once round the sun. By **axis** we mean the central line around which a planet rotates. Its **tilt** is the angle at which it lies to a line drawn at right angles to the direction of the sun. The planets revolve round the sun in different orbits which are all elliptical in shape (Fig. 1.1). The sun is always at one of the foci of these orbits. All the planets move in the same direction and very nearly in the same plane.

Some details about the planets relating to their mass, diameter ; density ; distance from the sun ; period of rotation ; period of revolution ; tilt of axis ; surface gravity etc., etc., are given in table 1.1 (page 4).

Mercury (*Budha*) :

Mercury is the planet nearest to the sun. It always appears in the same part of the sky as the sun, so very few people have ever seen it. Astronomers had to wait until the Mariner 10 space probe flew past mercury in 1974 to get a good look at its surface. The surface of mercury is marked by craters of all sizes caused by the impact of meteorites early in the planet's history. Due to extremes of temperature between day and night and absence of any atmosphere, no life is possible on this planet.

It is a small planet, but it is one of the densest. Astronomers believe that it has a large iron core.

It rotates slowly because the gravitational pull of the sun acts as a brake on Mercury's rate of spin.

As viewed from the earth ; its maximum **angular separation** from the sun can be 28°

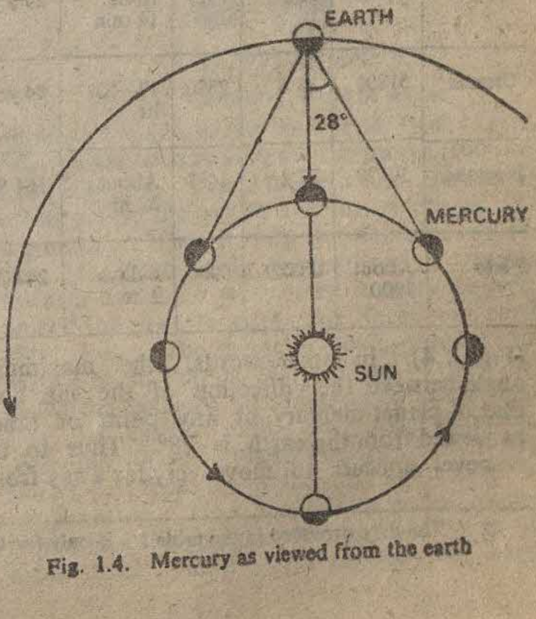


Fig. 1.4. Mercury as viewed from the earth

*Table 1·1. About Planets

Planet	Diameter (km)	Mass (Earth=1)	Average distance from the sun (million km)	Period of Rotation	Period of Revolution (Sidereal)	Tilt of Axis	Surface gravity (Earth=1)	Surface Temperature	Density 10^3 kg m^{-3}	No. of Satellites	Atmosphere
Mercury	4816	0·055	58	59 days	88 days	0°	0·4	340°C (by day) −175°C by night	5·43	0	None
Venus	12104	0·8	108	243 days	225 days	179°	0·9	475°C	5·24	0	Mainly carbon dioxide with clouds of sulphuric acid
Earth	12756 (at equator	1.000	150	23 hr 56 min 4 sec	365 days 6 hr 9 min 10 sec	23·4°	1·00	Max. 58°C Min. −88°C	5·52	1	Nitrogen and oxygen with clouds of water vapour
Mars	6787	0·107	228	24 hr 37 min 23 sec	687 days	24°	0·4	−70°C to 22°C	3·94	2	Mainly carbon dioxide, some nitrogen, argon and a little oxygen
Jupiter	142800	318	778	9 hr 50 min	11·9 yr	3°	2·6	−150°C at cloud level	1·33	16	Hydrogen, helium, ammonia, methane
Saturn	120200	95	1427	10 hr 14 min	29·5 yr	26·7°	1·1	−180°C	0·70	17	Hydrogen ; helium ; methane
Uranus	51800	14·6	2870	17—23 hr	84 yr	97·9°	1·1	−210°C	1.30	5	Hydrogen ; helium ; methane
Neptune	50100	17·2	4498	About 22 hr	164·8 yr	28·8°	1·2	−22°C	1·76	2	Hydrogen ; helium ; methane
Pluto	About 3000	0·0026 ?	5900	6 days 9 hr	247·7 yr	?	0·05 ?	About −230°C	1·1 ?	1	Probably none

(Fig. 1.4). In other words, the maximum angle between the direction of the sun and that of planet mercury, at any point of time, as viewed from the earth is 28°. Thus to us it never appears to move very far away from the sun. It, therefore, appears either as a morning star in the east (sometime before sun rise) or as an evening star in the west, sometime after sun set.

---

*The data provided in the table 1·1 is only for the information and the students need not memorize it.

Venus (*Shukra*) :

Venus is the second planet from the sun. Although it is further from the sun than mercury it is the hottest of all the planets. This is because it has an atmosphere which acts rather like the glass in a greenhouse to heat its surface. The day time temperature there is a sizzling 475°C, hot enough to melt several metals such as lead, tin and zinc.

Venus is almost the same size as the earth, but it is smothered in an atmosphere of carbon dioxide about a hundred times as dense as ours. Pressure on the surface is so dense that it is the same as the pressure 1000 metres deep in our ocean. Under these circumstances, there is no possibility of life on this planet.

Venus looks bright in our sky because it is the nearest planet to earth; and because it has a dense cover of white clouds which reflect the sunlight well. These clouds hold droplets of deadly sulphuric acid. The only view we have had beneath these dense clouds is from photographs taken by space probes. They show barren scenes of tumbled rock.

Venus rotates backwards compared to other planets, and turns once on its axis in 243 days (Fig. 1.5). A day on Venus lasts for over 7 earth years—from sun rise to sunset is over 3½ of our years. And the sun rises in the west and sets in the east: Astronomers describe its motion as **retrograde**. Venus has no strong magnetic field or radiation belts.

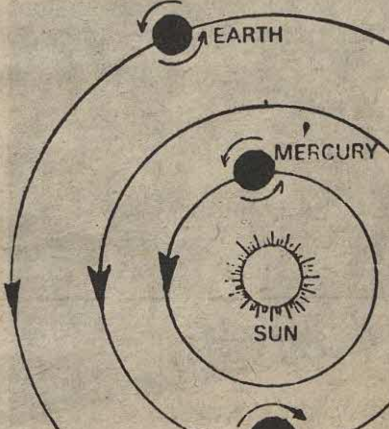


Fig. 1.5. Venus spins on its axis in the **opposite** direction to the other planets.

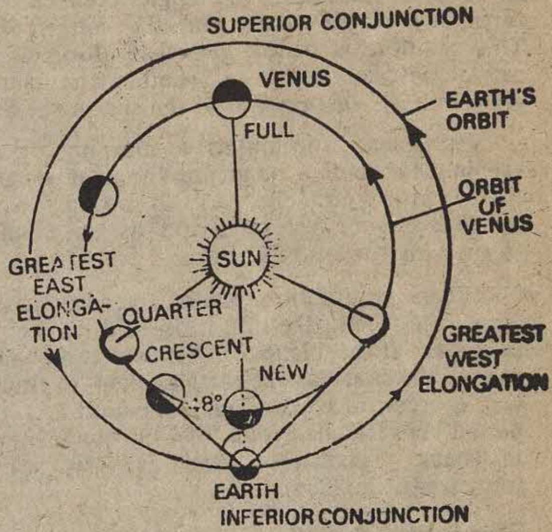


Fig. 1.6. Venus as viewed from Earth.

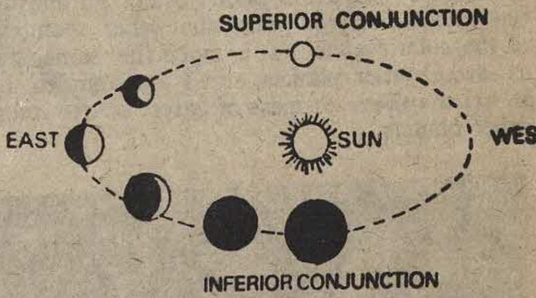


Fig. 1.7. Changing phases of Venus.

As the planet Venus travels round the sun, it goes through a complete cycle of phases from **new**, when it is completely dark, and close to the sun in the sky, to **full**, when its visible hemisphere is completely illuminated and it is opposite the sun in the sky, and back again. Why this is so is readily seen from the (Fig. 1.6) and (Fig. 1.7). Venus moves round the sun in orbits within the earth's and shows phases like the moon. When it is on the far side of the sun, its illuminated hemisphere is turned towards us, whilst when it is roughly between us and the sun, its dark side faces the earth (Fig. 1.6). The planets moving within the earth's orbit, that is, Mercury and Venus, are called the **inferior planets** whilst those outside the earth's path are the **superior planets**. When a planet lies in line with the sun as seen from the earth, it is said to be in **conjunction**. Now, the inferior planet, venus, comes into conjunction at two points in its orbit—once when it comes between the earth and the sun, **inferior conjunction**, and again when it is on the far side of the sun, **superior conjunction** (Fig. 1.6).

When venus is at its greatest apparent distance from the sun, the angle between the earth, the planet venus and the sun is 90°. This position is called **greatest elongation**, east or west depending on whether the planet appears to lie east or west of the sun in the sky.

Venus also appears as a morning or an evening star to us. Its greatest angular separation is nearly 48° (Fig. 1.6). It appears as a morning star for 292 days and as an evening star during the next 292 days.

When an inferior planet, · venus, passes across the face of the sun, it is said to be **in transit**. If the plane of Venus's orbit were exactly the same as the earth's, then a transit would occur once every synodic period *i.e.*, the period between successive inferior conjunctions of venus. Transit of venus is very scarce (next transit in 2004).

The Earth (*Prithvi*) :

In many ways, our planet is not an unusual one when compared with the other members of the solar system. It is much the same size as several other planets, and is surrounded by **an atmosphere** or mass of gases, as are most other planets.

Inside it has a core of hot liquid metal which gives the earth a magnetic field extending out into space. This is what causes compass needles to point north. However the reason for earth's magnetism is not wholly understood.

However, there is one big difference between the earth and the other planets, and its beautiful blue and white appearance is a clue to this difference—for no other planet **looks** like the earth. The difference is water—the blue of the oceans and the white of rain bearing clouds mark out our planet as a special place in the solar system. The possession of water gives earth life, for life as we know it depends on water. Most forms of life also need oxygen, which is in our atmosphere, and our atmosphere also protects us from harmful rays coming from the sun. The atmosphere is composed mainly of two gases, nitrogen (78%) and oxygen (20%). Carbon dioxide, water vapour and clouds prevent all the heat which reaches the ground from being reflected away again.

The earth is also unusual because it has one moon, other planets having either none or several moons. Our moon is comparatively large and the pull of its gravity raises the tides on earth (Fig. 1.10).

Motions of the Earth

The earth has four independent motions. (1) As a part of the solar system, the earth is moving in space along with the sun. However,

Fig. 1.8. The Earth seen from lunar orbit.

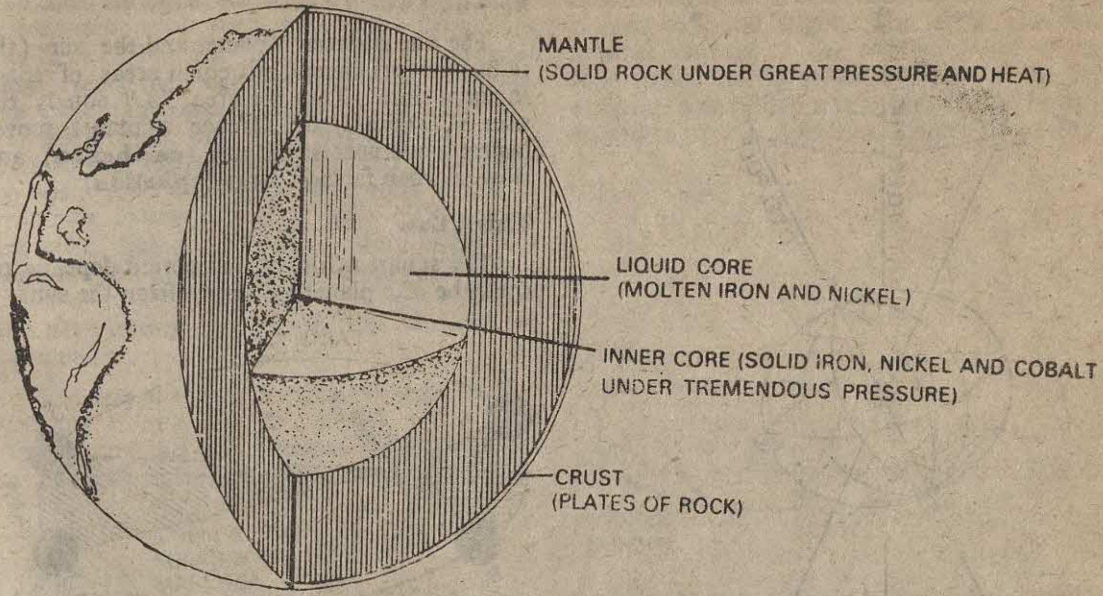

MANTLE
(SOLID ROCK UNDER GREAT PRESSURE AND HEAT)
LIQUID CORE
(MOLTEN IRON AND NICKEL)
INNER CORE (SOLID IRON, NICKEL AND COBALT
UNDER TREMENDOUS PRESSURE)
CRUST
(PLATES OF ROCK)

Fig. 1.9. What is the earth made of ?

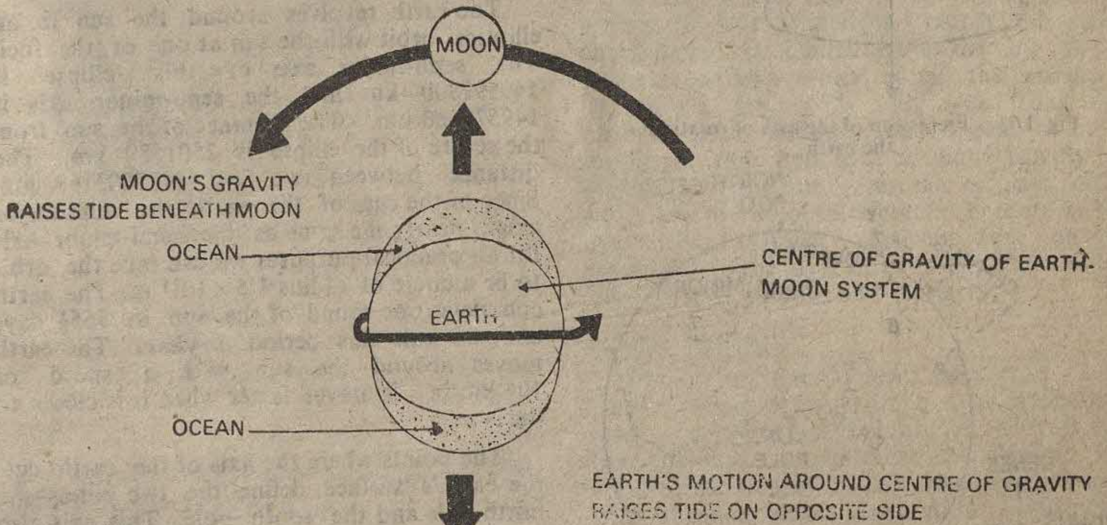

MOON
MOON'S GRAVITY
RAISES TIDE BENEATH MOON
OCEAN
CENTRE OF GRAVITY OF EARTH-
MOON SYSTEM
EARTH
OCEAN
EARTH'S MOTION AROUND CENTRE OF GRAVITY
RAISES TIDE ON OPPOSITE SIDE

Fig. 1.10. Tides

since the space is so vast and the stars are so far away from the earth, for centuries this motion has not produced any major observable effect. (2) The earth moves round the sun in an elliptical orbit with the sun at one of the foci. (3) The earth rotates about its own axis. (4) The axis of the earth also precesses like that of a spinning top (Fig. 1.11). However, this is a very slow motion and takes nearly 26000 years to complete one round. One consequence of this motion would be that in the distant future the axis of rotation of the earth will move away from the pole star. In A.D. 14000, it will be pointing towards the star Vega (Fig. 1.12).

Kepler put forward **three laws** of planetary motion as follows :

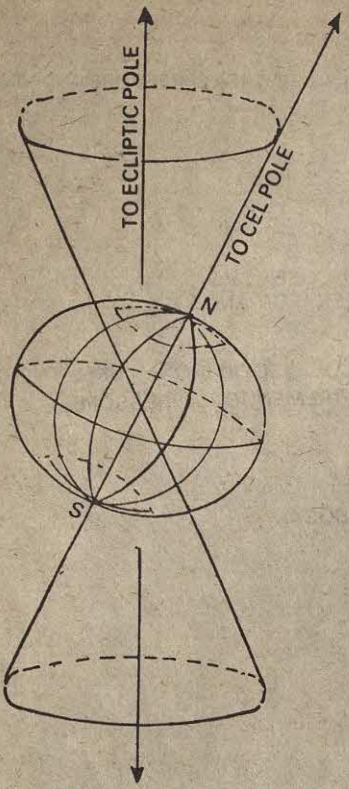


Fig 1.11. Precession of the axis of rotation of the earth.

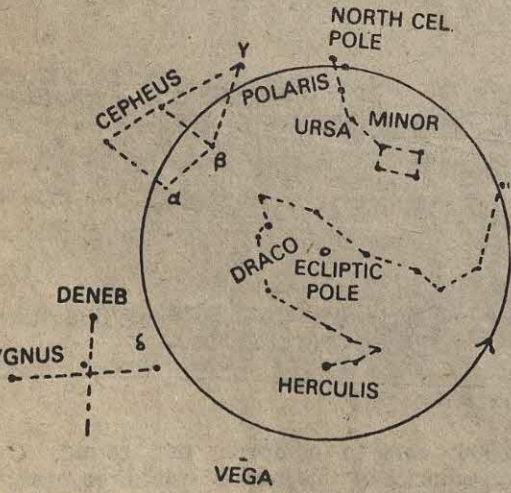


Fig. 1.12. Precessional Path of the North Celestial Pole. The celestial pole describes a circle having a radius of 23½ with the ecliptic pole at its centre.

Ist Law

Planets move around the sun in elliptical orbits with the sun at one focus of the ellipse.

Second Law

The line between a planet and the sun (the radius vector) sweeps out equal areas of space in equal time. Thus the area *SAB* equals the area *SCD* (Fig. 1.13). Hence a planet moves fastest when nearest the sun (**perihelion**) and slowest when farthest away (**aphelion**).

Third Law

The square of the orbital period depends on the cube of a planet's distance from the sun.

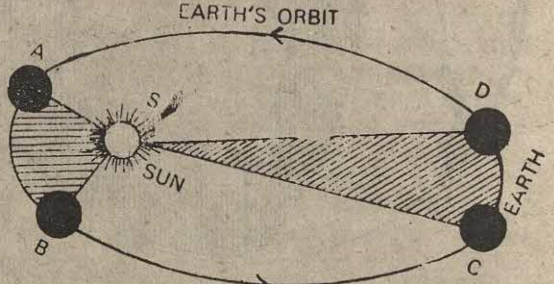


Fig. 1.13.

The earth revolves around the sun in an elliptical orbit with the sun at one of the foci. The semi-major axis of this ellipse is 149597800 km and the semi-minor axis is 149577000 km. The distance of the sun from the centre of the ellipse is 2501580 km. The distance between two foci is 5003160 km. Since in the case of the earth the semi-major axis is nearly the same as the semi-minor axis for all practical purposes we can take the orbit to be a circle of radius $1 \cdot 5 \times 10^{11}$ m. The earth completes one round of the sun in 365¼ days and we call this period a **year**. The earth moves around the sun with a speed of 10^5 km/h. It moves faster when it is closer to the sun.

The points where the axis of the earth cuts the earth's surface define the two poles—the north pole and the south pole. This axis also passes through the centre of the earth. The earth completes one rotation about its axis in 23 hours 56 minutes with respect to stars. But in the meantime earth also moves forward in its orbit. As a result the position of the sun as seen against the background of stars also changes in the space. Therefore to be in exactly the same position with respect to the sun the earth takes another four minutes. Thus the period of rotation of earth is taken as 24 hours (Fig 1.14). In other words if we reckon our day from one noon to the next noon, the earth rotates about 4° more than one complete rotation of 360°. The day reckoned on the basis of 360° rotation is called a **sidereal day**. Hence the length of the day is 24 hours, since the time measurement are done with reference to the sun. It rotates from west to east, so that the sun appears to move from east to west. The rotation of the earth about its own axis causes day and night. The part of the earth facing the sun receives light. The duration during which the sun is visible is called a day. Due to rotation, after sometime, this part moves away from the sun and we have night.

The axis of the earth makes an angle of 23½° with the normal to its orbital plane. The direction of the axis remains fixed in space as the earth travels round the sun [Fig 1.15]

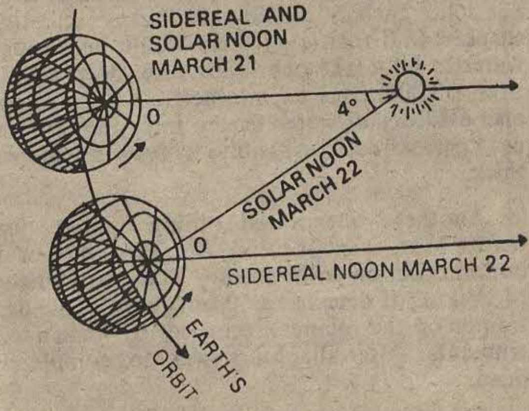


Fig. 1.14

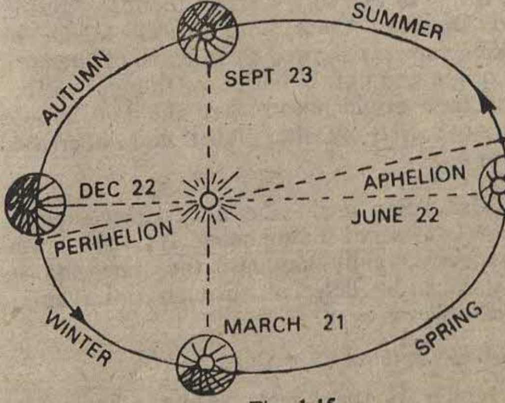


Fig 1.15

These two motions of the earth—rotation about an axis and revolution round the sun—are responsible for two separate apparent motions of the sun as seen by us on the earth. One is the Motion of the sun around the earth causing day and night. The other is a more gradual change in (*a*) the length of the day (and night), and (*b*) in the position of the sun at noon from a low angle above the horizon in winter to near zenith in summer [Fig 1.16]

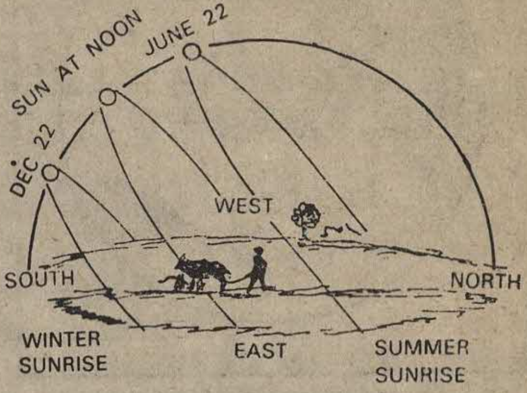


Fig. 1.16 Path of the sun in the sky during winter and summer

As mentioned earlier, the earth possesses a magnetic field. It attracts towards the poles charged particles emitted from the sun and it is these particles which cause the **aurorae**. The aurorae are usually only seen from high north or south latitudes. They appear as moving bands, rays and arcs of light usually of greenish or pink hue. Auroral displays often cause severe radio interference because of the effect that charged particles have on the **ionosphere**, the layer of the atmosphere which reflects radio waves round the earth.

MARS (*Mangal*) :

Mars is perhaps the most interesting of the planets, when seen through a telescope it is seen to have reddish colour ; at least it has been the object for the most speculation. We get the best view of it ; its surface can be seen without much cloud obscuration ; and of all the planets in the system other than earth, it seems the most likely to be hospitable to life.

The Martian day is almost the same as the terrestrial day : 24 hr, 37 min, 23 s. The Martian year is about two of our years. It is situated from the sun at a distance of about 1½ times as much as that of the earth. The planet exhibits white polar caps that grow large in winter and small in summer in step with the seasons. Other changes in certain greenish areas are also seasonal. Temperatures in the equa-

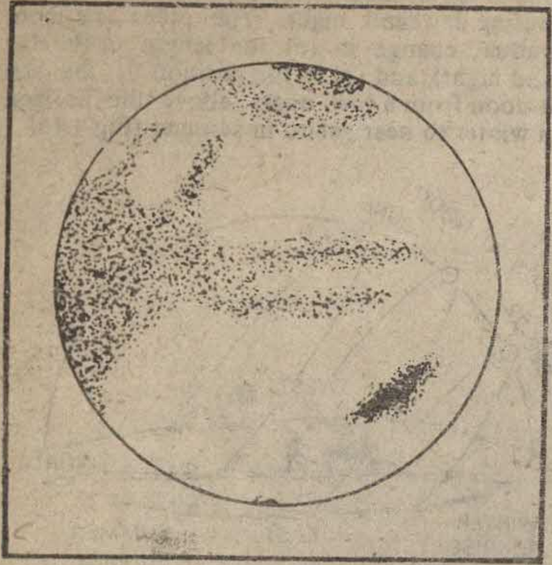


Fig. 1.17 The planet Mars as seen telescopically

torial regions tend to run from about 30°C during the day to perhaps −75°C at night. The temperature at the poles is about −130°C. The presence of earth-like conditions on Mars suggested the possibility of existence of some life on Mars.

The Mars vehicles sent by Russia and Mariner space probes sent by U.S.A., however, revealed that the ice caps were made of solid CO_2 with a small percentage of water in them. The photographs taken by Mariner 9 during 1971-72 showed that Mars has craters like those on the moon but the boundaries of these craters have been smoothened by the eroding action of strong winds which causes huge dust storms. Viking-I and Viking-II were sent by U.S.A. to find out if any life existed on Mars. Viking-I began on July 20, 1976, man's first ever search for life outside the third planet. Forty-five days later, the second craft, Viking-II landed further north about 7000 kilometres away. Between them the two crafts have sent back valuable data and remarkable pictures. But *Martian life, if it is there, still remains elusive.*

Viking Scientists argue that the failure detect organic material in Martian soil does not necessary prove that there is no life on t planet. "The search may not have been sufficiently thorough or we may have been looking at the wrong places, "says Vikings chief project scientist, Mr. G.A. Soffen Others like astronomer Zdenek Kopal of Manchester University, feel that "the results obtained so far leave no doubt that Mars has no life."

Even if the Vikings have disappointed many who expected to see at least some form of living matter (lichens etc) on the planet, they have yielded an enormous body of important information. Many of the findings have radically changed our ideas about Mars.

The Martian atmosphere turned out to be completely different from what was known earlier. Besides carbon-dioxide and oxygen, viking instruments found as much as 3 percent nitrogen which was thought to be virtually absent on the planet.

A major Viking discovery was that the ice of the polar caps is made of frozen water and not solid carbon dioxide as many scientists suspected. If that is so, there would be enough water to fill a lake one kilometre deep spread over 33,000 square kilometres ! There was also evidence of water frozen into the ground as "permafrost", possibly a few kilometres thick.

Another unexpected thing came just before Mars went behind the sun and out of communication with earth. The seismometer of Viking-II detected a "Marsquake", the first tremor on the planet recorded by man's instruments. After all, Mars was not completely dead.

The Viking missions also threw new light on the origin of two tiny Martian moons—**Phobos** and Deimos. Close up pictures taken by Viking cameras showed them to be of meteoritic origin and not besaltic as thought earlier. If so that would mean that the two moons were captured by the planet and not created from it.

Mars being outside the earth's orbit (superior planet), does not show phases. It moves comparatively rapidly amongst the stars and its motion can be detected through observations spread over a week.

Jupiter (*Brihaspati or Guru*) :—

Jupiter is the largest planet of the solar system. Runnings around it are wide bands of different colours, probably clouds, among which can always be seen the **Great Red Spot**, probably a continuous storm in the atmosphere. It has more than a dozen moons. A few of these are themselves quite large in size and on a clear dark night they can be seen with a low-power telescope.

The first person to observe Jupiter telescopically was Galileo in 1609, and even with his tiny telescope quite a lot could be seen on the planet.

Because Jupiter is so massive, its **escape velocity** is quite high and so it has been able to retain all the gases including hydrogen, the fastest moving of them all.

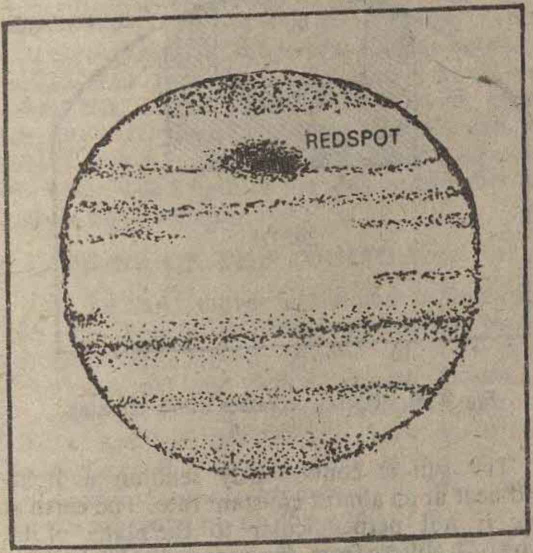


Fig. 1.18. The cloud belts of Jupiter.

In recent years it has become apparent that Jupiter is a source of radiowaves, though the origin of these waves remains a mystery.

Saturn (*Shani*)

Saturn is one of the most beautiful telescopic sights in the entire heavens, principally because of the system of rings, ; unique in the solar system, which surround the body of the planet. The rings are composed of particles and stones, possibly ice-covered, floating in belts only a few kilometres thick. They may be the remains of a moon that broke up.

The rings were discovered by Galileo in 1610. One can observe them easily with a low power telescope. Space probes have passed close to saturn and sent beautiful pictures of its ring system.

Uranus (*Arun*) :

Uranus was the first planet to be discovered by astronomer Herschel in 1781 with a telescope, although it can just be made out without one. It is greenish in colour, and probably has a surface of ice and frozen gases beneath swirling clouds. In 1977 it was discovered to have a ring system.

The most interesting feature of this planet is that it rotates about its axis from east to west in contrast to other planets which rotate from west to east. It has five moons, two of which, Titania and Oberon, were discovered by Herschel.

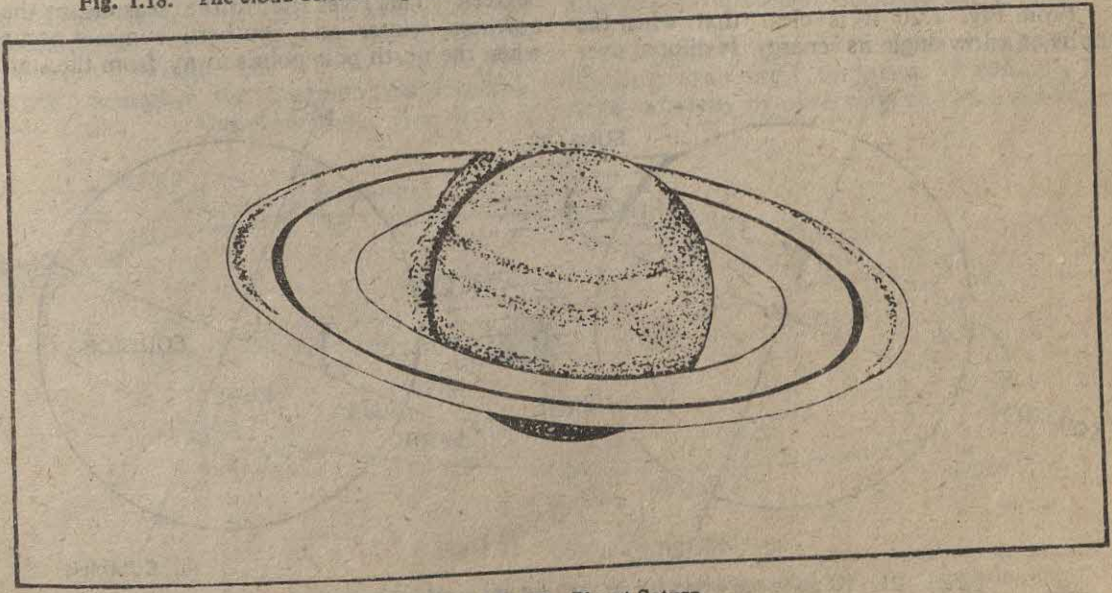


Fig. 1.19. The Planet Saturn.

Neptune (*Varun*)

Neptune has a blue tinge when seen in a telescope but no markings can be observed. It is probably like uranus. The existence of this planet was predicted in 1844 in order to explain the discrepancies in the orbit of Uranus. Neptune has two known satellites. The first of these is Triton, discovered a few weeks after the planet itself, one of the largest in the solar system. It moves in a near-circular retrograde orbit. The other moon, Nereid, has an extremely eccentric orbit.

Pluto (*Vam*)

Pluto is usually the most distant planet, but part of its orbit passes within that of Neptune. For this region Neptune will in fact be the most distant planet until about 2000. Pluto is a small planet and little is known about it, though it is thought to have once been a moon of Neptune. Its existence was predicted theoretically in an attempt to explain the perturbations in the orbits of Uranus and Neptune. It was discovered in 1930 by Clyde Tombaugh.

Travel out as far as Neptune or Pluto is certainly beyond our capabilities at present with manned craft and is likely to remain so for a long lime. A flight to Pluto and back could take many decades. From Pluto the Earth would be quite invisible, even telescopically.

1.4. CHANGE OF SEASONS

From Fig. 1.20 it is clear that when the sun is at a low angle its energy is diluted over a wide area. At a high angle, it is concentrated. This is an important finding and it has a direct bearing on our climate.

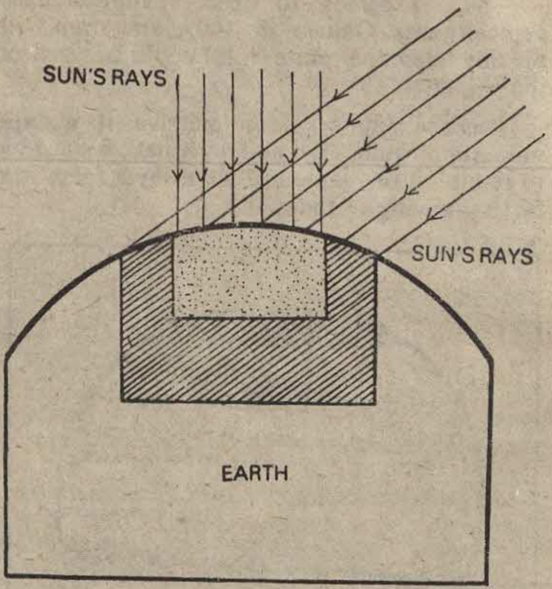
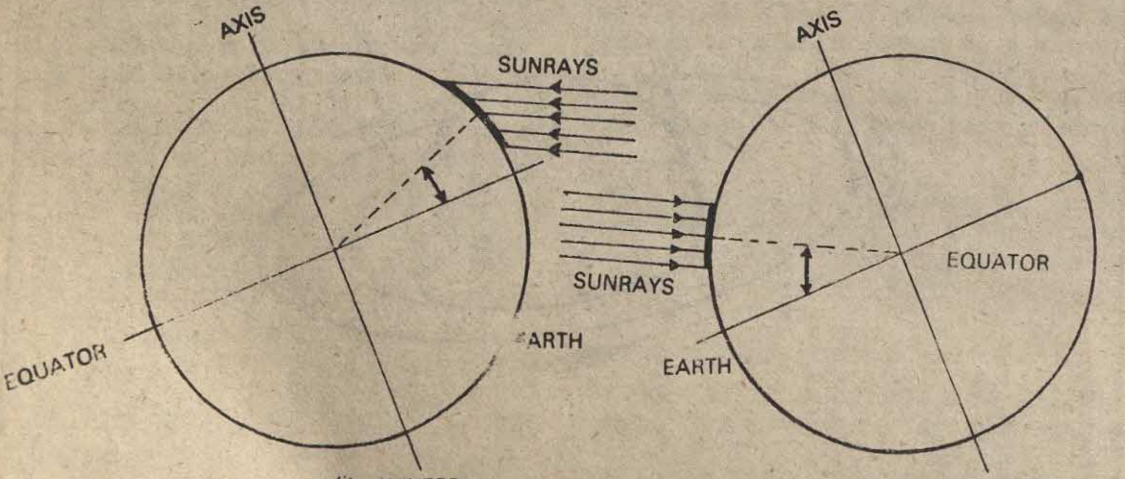


Fig. 1.20. Energy decreases with increasing inclination

The sun is continuously sending us light and heat at an almost constant rate. The earth's axis is not perpendicular to the plane of its orbit. It differs from the perpendicular by 23½ degrees. This gives rise to the seasons, as the northern winter and southern summer occur when the north pole points away from the sun,



(i) WINTER (ii) SUMMER

Fig. 1.21. At noon sun's rays (*i*) are inclined at considerable angle during winter and (*ii*) fall almost normally during summer.

while the northern summer and southern winter occur when the north pole points more towards the sun (Fig. 1.15). Southern summer occurs when the earth is near perihelion and moving fastest, and it thus tends to be hotter and shorter than the northern one.

All this can be explained by the fact that the angle that the normal to the earth's surface (at any one place) makes with the direction of the sun at noon (or any particular time) keeps changing from day to day. When the angle is small, the same energy of the sun falls on a smaller area, and we find the sun hot. This also corresponds to longer days (time between sunrise and sunset). Thus we have summers during this period. On the other hand, when the angle is large, the energy of the sun is spread over a bigger area and the sun appears less hot. The length of the day is also shorter and we have winters.

1.5. SIGNS OF THE ZODIAC

As the Earth moves on its path around the Sun, the Sun is projected against the background constellations (groups of stars that form patterns) and follows a path known as the **ecliptic**. The belt of sky, about 18 degrees wide, centred on the ecliptic, is known as the **Zodiac** and the constellations in this belt are the **Zodiacal constellations**. The Moon and planets all move within this band of sky.

The twelve constellations of the Zodiac are as follows : **Aries**, the Ram ; **Taurus**, the Bull ; **Gemini**, the Twins ; **Cancer**, the Crab ; **Leo** the Lion ; **Virgo**, the Virgin ; **Libra**, the Scales ; **Scorpius**, the Scorpion ; **Sagittarius**, the Archer ; **Capricornus**, the Goat ; **Aquarius**, the Water Carrier ; and **Pisces**, the Fishes. Starting at the first point in Aries, or *vernal equinox*, where the ecliptic intersects the *celestial equator in the northern hemisphere Spring, the Zodiac is divided into twelve zones 30 degrees wide. Each of these zones is assigned a 'sign of the Zodiac' corresponding to one of the twelve constellations named above, but the period during which the Sun lies in a particular sign does not correspond well with the time that it lies in the actual constellation of that name. The reasons for this are that the constellations are not of the same width, nor are they evenly spaced, and—most important—precession has caused the vernal equinox to move from Aries into Pisces. In a thousand years' time it will lie in Aquarius, and so it will move through the Zodiac, returning more or less to its present position in about 26,000 years.

The motion of the Sun through the Zodiac enabled the ancients to estimate the seasons and regulate their crops, and the Zodiac came to assume a position of prime importance in the study of astrology. Naturally enough in ancient times, the motions of the Sun, Moon and planets against the background of the Zodiac were thought to have profound influence on the course of man's affairs, and the influence on individuals was governed by the sign under which they were born. Astrology still claims some adherents today, but it has no scientific basis. Astronomers become most annoyed if confused with astrologers !

We cannot directly observe the position of the sun amongst the stars. It can only be done indirectly by observing the stars near the

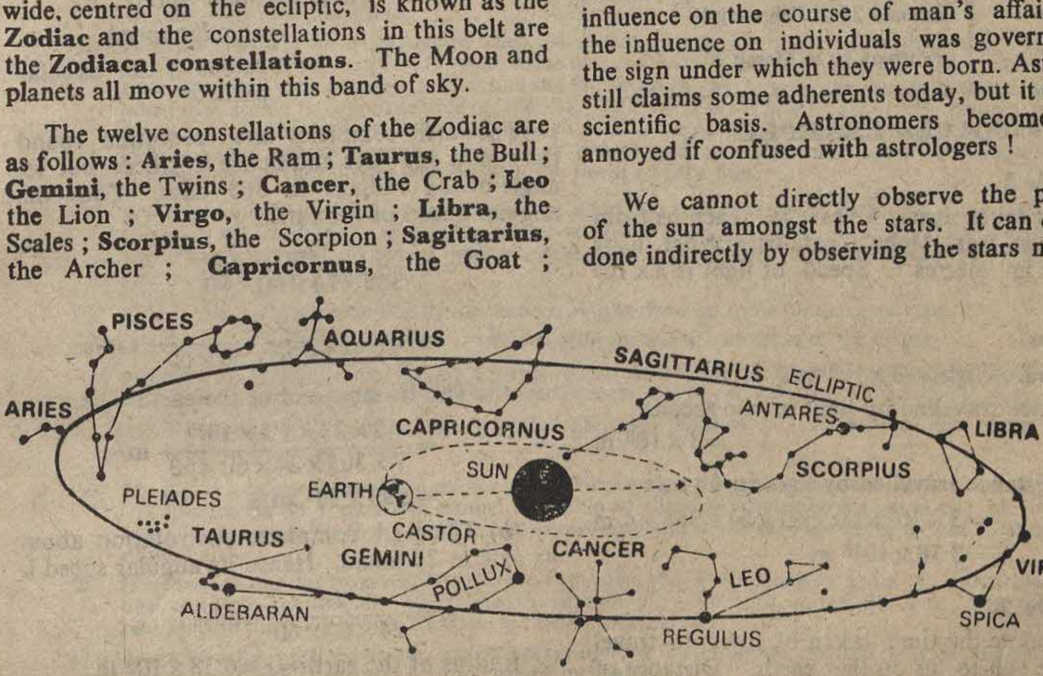


Fig. 1.22. Signs of the Zodiac

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*It is convenient to imagine that the stars are points on a huge sphere called the **celestial sphere**, with the earth at the centre. The zero line of celestial latitude is called the **celestial equator**. The celestial sphere appears to rotate round the earth from east to west.

horizon just before sun rise and just after sun set. Earth is nearest to the sun around January 1 (when it is winter in the northern hemisphere) and farthest around July 1 (when it is summer). The sun appears in different constellations during different parts of the year. The details are given in Table 1.2.

Table 1.2

Constellation	*Approximate Time of the Year*
Aries	March 21 to April 19
Taurus	April 20 to May 20
Gemini	May 21 to June 21
Cancer	June 22 to July 22
Leo	July 23 to August 22
Virgo	August 23 to September 22
Libra	September 23 to October 22
Scorpio	October 23 to November 21
Sagittarius	November 22 to December 21
Capricornus	December 22 to January 21
Aquarius	January 22 to February 18
Pisces	February 19 to March 20

SOLVED EXAMPLES

Example 1.

Light takes nearly 4 years to reach us from the nearest star, Alpha Centauri. What is its distance in metres ? Speed of light is 3×10^{8} m/s.

Solution.

Speed of light$=3\times10^{8}$ m/s

or distance travelled by light in one second

$$=3\times10^{8}\text{ m}$$

$\therefore$ distance travelled by light in 4 years

$$=3\times10^{8}\times60\times60\times24\times365\times4\text{ m}$$

$$=\mathbf{3\cdot78\times10^{16}\ m}$$

Example 2.

Calculate the time taken by light to travel from the sun to us on the earth. Distance of the sun from the earth is $1\cdot5\times10^{8}$ km and speed of light is 3×10^{8} m/s.

Solution.

Given,

Distance of the sun from the earth

$$=1\cdot5\times10^{8}\text{ km}$$

$$=1\cdot5\times10^{11}\text{ m}$$

Speed of light$=3\times10^{8}$ m/s

Since,

$$\text{Speed of light}=\frac{\text{distance covered}}{\text{Time taken}}$$

$$\therefore\ \text{Time taken}=\frac{\text{distance covered}}{\text{speed of light}}$$

$$=\frac{1\cdot5\times10^{11}}{3\times10^{8}}\text{ s}=\mathbf{500\ s}$$

Example 3.

Calculate (*a*) the speed of the earth as it travels round the sun ; (*b*) our speed as the earth rotates round its axis. Given : Distance of the earth from the sun is $1\cdot5\times10^{8}$ km ; Radius of the earth$=6\cdot38\times10^{3}$ km and one year$=365$ days.

Solution.

(*a*) We know that

$v=\omega r$ where $v=$linear speed

$\omega=$angular speed

$r=$radius of the circular path.

The earth completes one revolution round the sun in 365 days and hence it traces out an angle of 2π radians in 365 days. Thus the angular speed of the earth,

$$\omega=\frac{2\pi}{365\times24\times60\times60}$$

$$=\frac{2\times22}{7\times365\times24\times60\times60}\text{ rad/s}$$

$\therefore$ The linear speed of the earth$=\omega r$

$$=\frac{2\times22\times1\cdot5\times10^{11}}{7\times365\times24\times60\times60}\text{ m/s}$$

$$=\mathbf{2\cdot99\times10^{4}\ m/s}$$

(*b*) The earth completes one rotation about its axis in 24 hours. Hence its angular speed is

$$\omega=\frac{2\pi}{24\times60\times60}\text{ rad/s}$$

Radius of the earth$=r=6\cdot38\times10^{6}$ m.

$\therefore$ Our speed as the earth rotates round its axis$=v=\omega r$

$$=\frac{2\pi\times 6{\cdot}38\times 10^6}{24\times 60\times 60}\ \text{m/s}$$

$$=\frac{2\times 22\times 6{\cdot}38\times 10^6}{7\times 24\times 60\times 60}\ \text{m/s}$$

$$=\mathbf{4{\cdot}64\times 10^2\ m/s}$$

Example 4.

Calculate the density of the earth from the data given below. Consider the earth to be a sphere.

Mass of the earth $= 6\times 10^{24}$ kg

Radius of the earth $= 6{\cdot}4\times 10^3$ km

Solution

Volume of the earth $=\frac{4}{3}\pi r^3$ where r is the radius of the earth.

$$=\frac{4}{3}\times\frac{22}{7}\times(6{\cdot}4\times 10^6)^3\ \text{m}^3$$

Density of the earth

$$=\frac{\text{Mass of the earth}}{\text{Volume of the earth}}$$

$$=\frac{6\times 10^{24}}{\frac{4}{3}\times\frac{22}{7}\times(6{\cdot}4\times 10^6)^3}\ \text{kg m}^{-3}$$

$$=\mathbf{5{\cdot}5\times 10^3\ kg\ m^{-3}}.$$

SUMMARY

1. A good knowledge of the sky is a thoroughly pleasing thing, and the sight of the stars and planets shining against the background of the Milky Way in a clear sky is still perhaps the most moving experience in the whole of astronomy.

2. The Earth on which we live is simply one of a family of planets revolving around the sun, while the sun itself is no more than one very ordinary star in the huge stellar system. The sun is the nearest star to the Earth.

3. Planets are solid bodies like the Earth with no light of their own, shining by reflected sunlight. They are the *wandering stars* as they were known to ancients.

4. The Sun carries with it in its journey through space not only the nine planets, but a host of other minor bodies, such as comets, meteors and the minor planets or asteroids.

5. The planets are, in order from the Sun : Mercury ; Venus ; Earth ; Mars ; Jupiter ; Saturn ; Uranus ; Neptune and Pluto.

6. A planet is said to be in *conjunction* when it is in line with the sun as seen from the earth. The inner two planets, Mercury and Venus, come into conjunction at two points in their paths—once when they pass between the Sun and the Earth (known as *inferior conjunction*) and again when they are on the opposite side of the Sun (*superior conjunction*). The inner planets are known as *inferior planets* and they go through a complete cycle of *phases*. The outer planets (known as the *superior planets*) do not show phases and they can only come into superior conjunction. for they do not pass between the Earth and the Sun.

7. When an outer planet is opposite the Sun in the sky that is, when Sun, Earth and planet are in line with the Earth in the middle, the planet is said to be in *opposition*. It is then at its nearest and appears brightest. When an inner planet is at its farthest point in the sky from the sun, it is said to be at *greatest elongation*.

8. In order to explain the motion of the planets, Kepler drew up three fundamental laws :
   (*i*) Planets move around the sun in ellipses, with the sun at one focus of the ellipse.
   (*ii*) The line (radius vector) joining a planet to the sun sweeps out equal areas of space in equal times. Thus a planet moves fastest when nearest the sun and slowest when farthest away.
   (*iii*) The square of the time taken to complete an orbit depends on the cube of the planet's distance from the sun.

9. The Earth has four independent motions : (*i*) The Earth is moving in space along with the Sun (*ii*) The revolution of the Earth around the sun in an elliptical orbit with the sun at one of the foci (*iii*) The rotation of the Earth about its own axis and (*iv*) Precession of the axis of rotation of the Earth.

10. If we reckon our day from one noon to the next noon, the Earth rotates about 4° more than one complete rotation of 360°. This is because of its motion round the sun. The day reckoned on the basis of 360° rotation is called a *sidereal day*.

11. *Energy density* is defined as the incident energy divided by the area on which it is incident. The energy density decreases with increasing inclination.

    When the sun is at a low angle, its energy is diluted over a wide area. At a high angle it is concentrated.

12. As the Earth orbits the Sun, the tilt of its axis gives rise to the *seasons*—Spring, Summer, Autumn and Winter. This is because there are periodic variations in the amount of sunlight reaching the northern and southern hemispheres.

13. The apparent track of the sun in mid winter, spring and autumn, and mid-summer, shows how the noon elevation and the duration of day light vary with the seasons.

14. As the earth moves round the sun in its orbit, to us it appears as if the sun is revolving round us against the back ground of the distant stars. It completes one revolution in one year. The path of the sun amongst the stars is known as the *ecliptic*. The stars along this path have been grouped into 12 constellations to help in describing the position of the sun. These constellations are known as the *signs of the Zod'ac*. They are : *Aries*, *Taurus* ; *Gemini*, *Cancer*, *Leo* ; *Virgo* ; *Libra* ; *Scorpio* ; *Sagittarius* ; *Capricornus* ; *Aquarius* and *Pisces*.

QUESTIONS

[A] Objective-Type Questions

1. The sun is a
   (*i*) planet
   (*ii*) comet
   (*iii*) star
   (*iv*) asteroid

2. The solar system consists of
   (*a*) nine planets only
   (*b*) nine planets and their moons
   (*c*) nine planets and their moons as well as asteroids
   (*d*) nine planets and their moons moving around the sun, as well as asteroids.

3. .... is the smallest planet and also the nearest to the sun.

4. The time a planet takes to turn once itself is called the........ .. It is the length of planet's...........

5. The ....is the planet's year.

6. By...... .....we mean the central line around which a planet rotates. Its...........is the angle at which it lies to a line drawn at right angles to the direction of the sun.

7. ....is usually the most distant planet.

8. ....was the first planet to be discovered with a telescope.

9. ....with its many rings is the most beautiful sight in the solar system.

10. One light year is equal to...........metres.

[B] Very Short Answer-Type Questions

1. What is the speed of light ?
2. What is a light year ?
3. What is the approximate mass of the sun ?
4. What is the radius of the sun ?
5. What is the average distance of the earth from the sun ?
6. What is the mass of the earth ?
7. What is the radius of the earth ?
8 Is the Earth a planet ?
9. What is the surface temperature of the sun ?

10. Is the orbit of the earth circular or elliptical ?
11. Name the main source of energy in the solar system.
12. At what rate is energy being radiated by the sun ?
13. At what rate is the energy being received by the earth on the top of the atmosphere ?
14. What is the maximum angular separation between the direction of the sun and that of planet Mercury, as viewed from the earth ?
15. Name a planet that appears as a morning or an evening star to us.
16. Name two planets which show phases like the moon.
17. Name three planets which do not show phases like the moon.
18. When do we see **full** Venus ?
19. Name a planet that has two small natural satellites and appears slightly reddish.
20. Name a planet which is most massive and has more than a dozen moons.
21. What is a year ?
22. What causes day and night ?
23. Does the earth rotate about its axis from east to west or from west to east ?
24. How does the sun appear to move in the sky—from east to west or west to east ?
25. What is the angle that the axis of the earth makes with the normal to its orbital plane ?
26. Does the axis of the earth precess like that of a spinning top ?
27. During which approximate time of the year the sun appears in cancer ?
28. Name a planet which appears as a morning star for 292 days and as an evening star during the next 292 days.
29. What is the maximum angular separation between the direction of the sum and that of Venus as viewed from the earth ?
30. Write one characteristic of each of the planets : (*i*) Venus and (*ii*) Saturn. [*A.I.S.S. 1987*]

[C] Short-Answer Type and Essay-Type Questions

1. What is a star ? Is our sun a star ?
2. What is a planet ? How does it differ from a star ?
3. What is the solar system ? Name the various planets in our solar system.
4. Explain, why Venus shows phases like the moon whereas Mars does not.
5. Explain the apparent motion of the sun amongst the stars. How can it be observed ?
6. It is observed that the earth moves in an elliptical orbit with foci X and Y as shown in Fig (1.23). Its speed is greater when it is at X. Where is the sun located ?

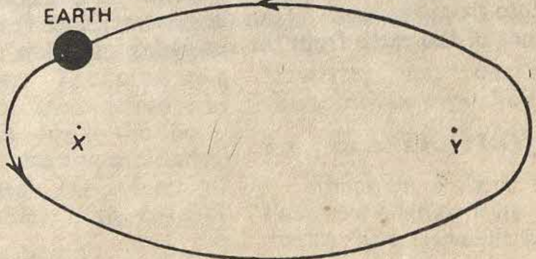

Fig. 1.23

7. In which part of the sky should one look for Venus ?

8. At any place (away from the equator) certain stars are visible throughout the year. They neither rise nor set. Which are these stars ? Explain your answer.

9. Comment on the direction of the axis of rotation of the earth. How does one explain the change in seasons on the earth ?

10. Name the various parameters of the earth. What is a sidereal day ?

11. Does the sun always rise at the same spot ? Explain.

12. (*a*) What is ecliptic ?

(*b*) What are signs of the Zodiac ? Name them.

(*c*) In which month of the year, the earth is nearest to the sun ?

13. (*a*) What are the four independent motions of the earth ? [*A.I.S.S. 1987*]

(*b*) With what linear speed does the earth revolve round the sun ?

(*c*) Define poles of the earth. Explain what causes day and night.

(*d*) What is the distance of the earth from the sun ?

14. State Kepler's laws of planetary motion.

15. The earth completes one rotation about its axis in 23 hours 56 minutes with respect to stars. But the length of the day is taken as 24 hours. Explain why ?

16. Why is the sun considered to be the head of the solar family ? Is the sun at the centre of the solar system ?

17. What are orbits ? What is the nature of the orbit of Jupiter ? What is the position of the sun in its orbit ?

18. Draw a diagram showing the journey of the earth round the sun, 'depicting the various seasons and the approximate time of the year. Also indicate the *perihelion* and aphelion of the earth.

PROBLEMS

1. Moon is at a distance of about $3{\cdot}8 \times 10^8$ m from us. How much time will light take to travel from the earth to the moon ? Speed of light is 3×10^5 km/s. [**Ans.** 1·3 s]

2. Calculate the density of the sun from the following data, considering it to be a sphere.

Mass of the sun$\approx 2 \times 10^{30}$ kg.

Radius of the sun$\approx 7 \times 10^8$ m [**Ans.** $1{\cdot}4 \times 10^3$ kg m^{-3}]

3. Calculate the time taken by light to travel a distance of $3{\cdot}78 \times 10^{16}$ m. Speed of light is 3×10^{10} cm/s. [**Ans.** $1{\cdot}26 \times 10^8$ seconds]

4. From the data given below, calculate the speed of the Mars as it travels round the sun.

Distance of the Mars from the Sun$\approx 2{\cdot}3 \times 10^8$ m

Period of revolution of the Mars$\approx$687 earth days [**Ans.** 25·4 m/s]

5. Using a scale, 1 m=distance of the earth from the sun, calculate in metres the distance of the planet Pluto from the sun. Mean distance of Pluto from the sun$=5936 \times 10^6$ km and mean distance of the earth from the sun is $1{\cdot}5 \times 10^8$ km. [**Ans.** 39·57 m]

CHAPTER 2

States of Matter

2.1. INTRODUCTION

The major objective of this chapter is to enable students to distinguish between various properties of solids, liquids and gases on the basis of their structure and molecular forces existing between the particles.

The concept of elasticity, phenomenon of surface tension, Archimede's principle and Bernoulli's principle have been discussed and explained by taking interesting examples from daily life.

2.2. STATES OF MATTER

The theory about the structure of matter is based on three principles :

(*i*) Matter consists of molecules

(*ii*) Molecules are in constant rapid motion

(*iii*) Molecules attract one another with a force which decreases as they go farther apart. When the molecules are of the same kind, the force of attraction is known as *cohesion* but when the molecules are of different kinds *e.g*, a water molecule and a salt molecule, the force of attraction is known as *adhesion*.

This theory enables us to explain the three states in which matter exists.

(*a*) Gaseous state :

A gas has neither a fixed size nor shape *i.e.*, it fills the whole of the space open to it. Molecules in gases are regarded as moving about freely and not to any great extent under the influence of each other's action except at impact of one on the other. The pressure a gas exerts on the walls of the enclosure in which the gas is contained is due to the bombardment of these rapidly moving molecules. There is almost no cohesion (*i.e.*, force of attraction) and the molecules in the case of gases are highly active.

(*b*) Liquid State :

A liquid has definite size but no shape. It would take up the shape of the vessel in which it is poured. Molecules in the case of liquids are closer together than in the case of gases and are quite free to move about from one part of the liquid to another. Liquids maintain a fixed volume on account of cohesion.

(*c*) Solid State

A solid has both a definite size and shape, which it does not readily relinquish. Molecules in solids are still closer together than in liquids. The force of attraction between the molecules is quite strong to keep the individual molecules in a fixed position of equilibrium but they remain oscillating about their mean positions.

We can classify solids into two main groups—**Crystalline** and **amorphous**. A crystalline solid is a substance solidified in a definite geometrical form. You are probable familiar with the shiny regular faces of copper sulphate, alum, mica and sugar crystals. Compare these with the dull appearance of the amorphous materials like flour, talc powder, glass etc. In an amorphous substance, the molecules are not clearly arranged in a definite geometrical pattern. An amorphous solid has no definite melting point whereas a crystalline solid has a definite melting point at which it becomes a liquid. Into which group do the metals fit ? They can be polished very readily and their bright lustre would seem to indicate that they should be associated with the crystalline rather than amorphous materials. However, they do not seem to have the characteristic crystalline planes and faces.

2.3. ELASTIC PROPERTIES OF SOLIDS

Whenever a force is applied on a body, there is a change in its length, volume or shape due to the relative displacement of the particles and as soon as this deforming force is removed, the body regains its original length, volume or shape owing to the reaction set up in the body itself. The body is said to be elastic and this power of recovery is known as *elasticity*.

Elasticity may, therefore, be defined as that property of matter by virtue of which a body endeavours to return to its original shape and dimensions when strained, the recovery taking place after the deforming force has been removed.

Stress is the *force of reaction* set up in the body itself by the deforming force. It is, therefore, the restoring force in the body and by Newton's Third Law of Motion, it is equal and opposite to the deforming force in all general cases. *Stress is measured as deforming force per unit area of the face where the force is applied.*

$$\text{Stress}=\frac{\text{Force}}{\text{area}}=\frac{F}{A}$$

It is measured in **newton/metre^2 or** N/m^2.

Strain is the ratio of deformation whether of length, volume or shape produced in a body by a deforming force.

Thus strain is of three types :

(*i*) *Longitudinal Strain*$=\dfrac{\text{Change in length}}{\text{original length}}$

$$=\frac{l}{L}$$

(*ii*) *Volumetric strain*$=\dfrac{\text{Change in volume}}{\text{original volume}}$

$$=\frac{v}{V}$$

(*iii*) *Shearing strain.*

It is measured by the angle $\angle ADA'=\theta$ known as angle of shear. It is the angle through which the various layers of a body get sheared when a force is applied on it.

Strain has *no unit* as it is the ratio of two similar physical quantities.

When a deforming force is applied on a body it is found that the strain produced in certain cases is so much that body fails to return completely to its original form and volume, or it retains a *permanent set*. The largest strain of any kind which a body may undergo and still completely recover when the deforming force is removed is called the **elastic limit**. This limit of elasticity is different for different substances, for instance, greater for rubber than for glass.

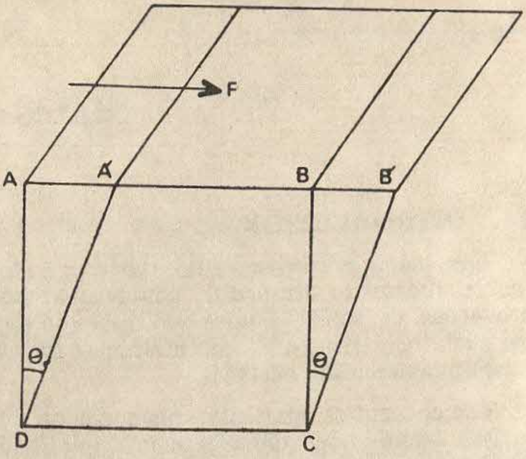

Fig. 2.1

It is found that *before the elastic limit is reached the stress applied is always proportional to the strain produced.* This fact was first noted by Hooke and is known as **Hooke's Law**. Hooke's Law thus states, that *stress is always proportional to the strain provided elastic limit is not attained.*

$$\text{Stress} \infty \text{ Strain}$$

or $$\frac{\text{Stress}}{\text{Strain}}=\text{a constant.}$$

This constant is known as **modulus of elasticity.**

When the strain is *longitudinal i.e.*, change in length only, the modulus of elasticity is known as **Young's Modulus.**

$$\text{Young's Modulus }(Y)=\frac{\text{Stress}}{\text{Longitudinal strain}}$$

$$=\frac{F/A}{l/L}$$

$$=\frac{F}{A}\cdot\frac{L}{l}$$

In case of a wire, $A=\pi r^2$ where r is the radius of a wire.

$$\therefore \qquad Y=\frac{F}{\pi r^2}\cdot\frac{L}{l} \text{ for a wire.}$$

It is measured in **newton/metre^2** or N/m^2

Determination of Young's Modulus for a given wire :

Take a long wire of length 'L' and area of cross-section 'a'. Suspend it at its upper end

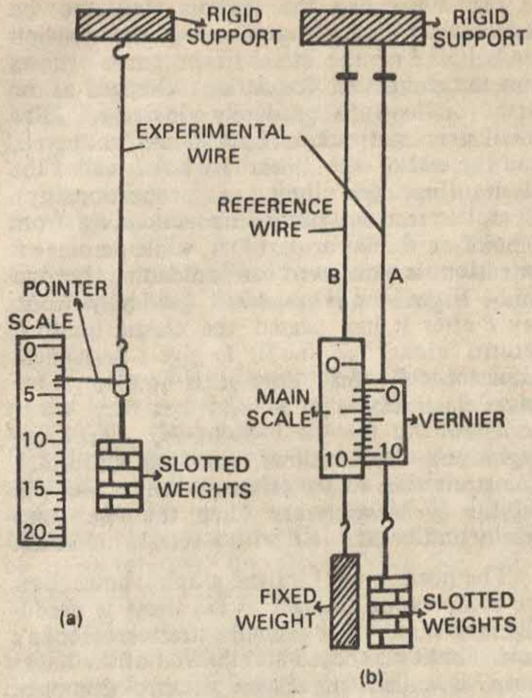

Fig. 2.2

from a rigid support and attach a hanger to its lower end in which the slotted weights can be placed. A pointer, attached very near to the hanger, moves along a vertical scale with the help of which changes in its position can be easily read (Fig. 2.2 (*a*). Place a weight of $\frac{1}{2}$ kg in the hanger and read the position of the pointer, and then gradually increase the weight in the hanger in equal steps and note down the change in the position of the pointer due to each addition. It will be seen that the increase in the length of the wire is proportional to the increase in the weight placed in the hanger. Further, when the weights are removed from the hanger in the same equal steps, the pointer returns to its original position.

If, however, we continue increasing the weight in the hanger, a limit will be reached, when it will no longer obey Hooke's Law. The increase in length will, therefore, be no longer proportional to the weight added, in the hanger, so that, on removing the weight, it does not return to its original position, and a permanent *"set"* is said to have occurred. Therefore, *it is necessary that in determining the value of Young's modulus the wire must not be stretched beyond the limit of elasticity.*

Now, to calculate its value, find the elongation each time the weight of $\frac{1}{2}$ kg is added in the hanger, also find the contraction each time the weight of $\frac{1}{2}$ kg is removed and get their mean value. Let this be equal to l; then Young's Modulus

$$Y=\frac{F}{a}\times\frac{L}{l}$$

If $F=\frac{1}{2}\times 9{\cdot}8N$ and L, l are expressed in *m* and a is expressed in m^2, then

$$Y=\frac{(\frac{1}{2}\times 9{\cdot}8)}{a}\times\frac{L}{l}\,N/m^2$$

The simple arrangement described above does not give good results on account of the following *sources of error* :

(*i*) The yielding of the support may cause an error in noting the true extension of the wire.

(*ii*) Any change in temperature during the experiment may affect the length of the wire.

To get rid of these errors, various arrangements are used. The usual arrangement for junior classes is shown in Fig. 2.2 (*b*) where *A* and *B* are two wires of the *same length and the same material and area of cross-section suspended from the support.* The wire *B* is loaded with a fixed weight to keep it stretched or taut, carries a main scale and merely acts as a *reference wire.* The wire A carries a hanger and a Vernier scale, and, on being loaded

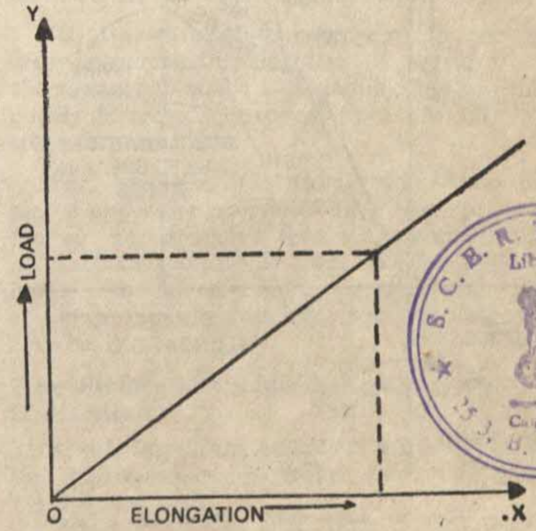

Fig. 2.3

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increases in length and hence it is called the *experimental wire.* Its elongation is indicated by the motion of the Vernier scale relative to the main scale on *B*.

In practice, a graph is drawn with the load as ordinate and the corresponding elongation as abscissa. The graph is found to be a straight line Fig. 2 3, within the limits of elasticity *showing that Hook's Law is obeyed.* Any suitable elongation and the corresponding load may be taken from the graph and Young's Modulus for a wire is calculated as explained.

Value of Young's Modulus for some common materials.

Material			Young's Modulus
Copper	...	...	$1\cdot2\times10^{11}$ N/m^2
Iron	...	...	$1\cdot9\times10^{11}$ "
Brass	...	...	$1\cdot0\times10^{11}$ "
Lead	...	...	$0\cdot16\times10^{11}$ "
Wood	...	...	$0\cdot1\times10^{11}$ "
Rubber	...	...	$10\cdot0$ "
Glass	..	...	$0\cdot6\times10^{11}$ "
Steel	...	...	$2\cdot0\times10^{11}$ "
Tungsten	...	...	$3\cdot60\times10^{11}$ "

Stresse-Strain Curve :—

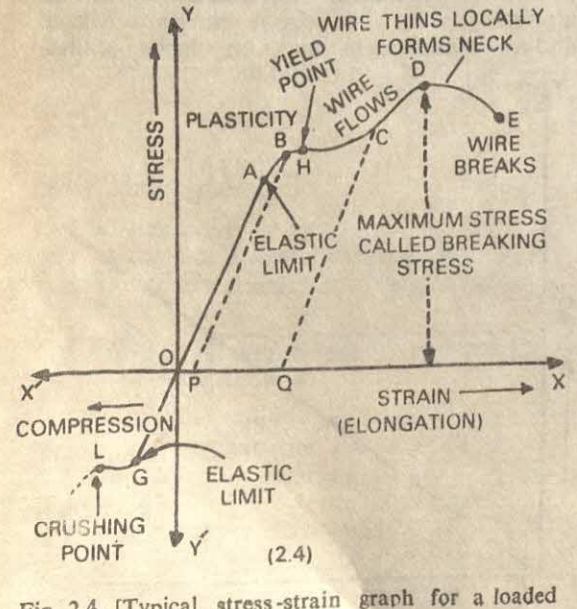

Fig. 2.4. [Typical stress-strain graph for a loaded (or compressed) wire]

Fig. 2.4 shows the various stages to be expected in the loading of wire. The portion OABHCDE of the stress-strain curve shows how the elongation (or strain) changes as the stress (or load) is gradually increased. For small stresses, Hooke's Law should be obeyed, and the end of the linear part A is called the *elastic limit* (or limit of proportionality). Complete recovery occurs on unloading from a point on the linear part OA, while permanent extension is observed on unloading beyond this. If the wire is unloaded gradually from, say *B* after it has passed the elastic limit, it returns along the line BP to give a permanent extension *OP*. Next time it is loaded, it behaves elastically as far as *B* ; it has been *work-hardened.* At the yield point *H*, *plastic flow* begins and the wire flows, thinning uniformly. The stress rises to a maximum, which we will call the *breaking stress.* Then the wire thins locally and breaks at *E* with a release of stress.

The portion OGL of the graph shows how the compression changes as the stress is gradually increased. For small stresses, Hooke's Law should be obeyed and the end of the linear part *G* is called the elastic limit. Complete recovery occurs on unloading from a point on the linear part OG ; while permanent extension is observed on unloading from beyond *G* and then the solid behaves like a plastic body. The yield point *L* obtained under compression is known as the *crushing point.* After this point, the solids can be hammered or rolled into sheets.

Properties of Materials with respect to Stress-strain curve :

The various mechanical properties of solids viz. elasticity ; plasticity ; brittleness ; ductility and malleability with respect to stress-strain curve Fig. 2.4 are discussed as follows :—

(*i*) **Elasticity.** When the stress is small, the solid completely regains its original shape, size or volume after the deforming force is removed. The solid is then said to be **elastic.** The linear portion *OA* (or *OG*) of stress-strain graph corresponds to the elastic behaviour of the solid. Between *O* and *A* and *O* and *G*, the strain is directly proportional to the stress and hence Hooke's Law is obyed. Steel, glass ; ivory etc., are elastic bodies.

(*ii*) **Plasticity.** When the stress is increased, a limit is reached beyond which, if the stress is removed, the solid does not come back to its original shape or size. It acquires a permanent deformation. This limit is called the elastic limit. The points *A* and *G* correspond to this limit. Beyond the elastic limit the solid behaves like a *plastic body i.e.*, the deformation of the body may continue under the influence of its own weight. The body is then said to *flow*. For example plasticine, putty : a paste of flour etc., flow under their own weight. Plastic bodies retain elongation or compression if the stress is removed. Recovery is no longer complete.

(*iii*) **Ductility** The point H beyond which a solid flows is called the yield point. Metals beyond the yield point are said to be *ductile*. Ductility is the property by virtue of which a solid can be drawn into wires. Silver, gold, copper etc. are good examples of ductility. Platinum is the most ductile metal. Quartz can be drawn into such fine threads that they cannot be seen with the naked eye.

(*iv*) **Brittleness**. The behaviour of different bodies is different when subjected to a deforming force. **A brittle** material such as a glass is that which fractures almost immediately after the elastic stage A when the deforming force is applied. Little or no plastic deformation occurs. It breaks into pieces.

(*v*) **Malleability**. Whenever a solid is compressed, a stage is reached beyond which it cannot recover its original shape, size or volume after the deforming force is removed. This is the elastic limit *G* for compression. The yield point obtained under compression is called the *crushing point*. After this stage, metals can be hammered, pressed, bent, rolled, cut or stretched into useful shapes. This property is known as **malleability**. Copper, gold, silver ; aluminium and lead can be easily hammered into sheets. Gold is the most malleable metal. It can be beaten into plates so thin that it would require several hundred thousand of them, one above the other, to make a layer one centimetre thick.

2.4. FLUIDS

The word fluid is used both for liquids and gases.

A fluid is called a perfect fluid.

(*i*) *if its shape can be altered by any tangential force, however small, when applied for a sufficient time,*

(*ii*) *if its portion can be separated easily from the rest of the fluid, and*

(*iii*) *if there is no force of friction between its different portions.*

There is no *fluid* in which this force of friction does not exist. For example, when water is set revolving in a cup by means of a spoon it soon comes to rest on account of :

(*a*) the frictional resistance between the water and the walls of the cup, and

(*b*) the frictional resistance between the different portions of the water.

The water in motion is an imperfect fluid but water at rest is practically equivalent to a perfect fluid.

Fluids are divided into two classes, *i.e.*, LIQUIDS and GASES.

(*i*) **Liquids** are those fluids which are almost entirely incompressible. A substance is called incompressible if its *volume* cannot be changed by the application of a force, however great, but its *shape* would change by the application of a force, however small.

All liquids are, however, compressible to a *small* extent. For example, a pressure of 200 atmosphere will decrease the volume of 100 cm^3 of water by about 0·9 cm^3.

For all practical purposes, this small compressibility will be neglected and it will be assumed that all liquids are incompressible.

(*ii*) **Gases** are those fluids which can be easily compressed by increase of pressure. If the pressure to which a gas is subjected is sufficiently decreased, it expands so as to fill any space, however large.

For example, if a child's air-balloon be placed under the receiver of an air-pump, and the air be exhausted from the receiver, the balloon will increase in size. If the balloon bursts, the air contained in it will fill the entire space of the receiver, however large it may be.

Free Surface of a Liquid at rest is always Horizontal :

A very important property of a liquid is that its free surface is always horizontal provided it is at rest.

Let us suppose that the free surface of a liquid at rest is *not horizontal* but is *curved.*

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Let the curved surface be represented by *PQRSTU* (Fig. 2.5). Imagine an inclined plane through *QS*. The weight, *W*, of the liquid lying above the inclined plane *QS* has a tendency to pull it down the inclined plane. In other words, the liquid begins to *move* down the inclined plane *QS* as a perfect fluid must yield to a tangential force, however small it may be. But this is against our assumption that the liquid is at rest. Hence the free surface of a liquid at rest is always *horizontal.*

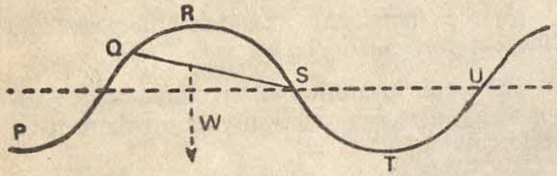


Fig. 2.5

The above fact may be put in a different language by saying that a liquid finds its own level. This may be demonstrated by taking three tubes *P*, *Q* and *R* of different shapes but connected together to a horizontal tube *AB* (Fig. 2.6). When a liquid is poured in one of the tubes, it stands at the *same* level in all of them.

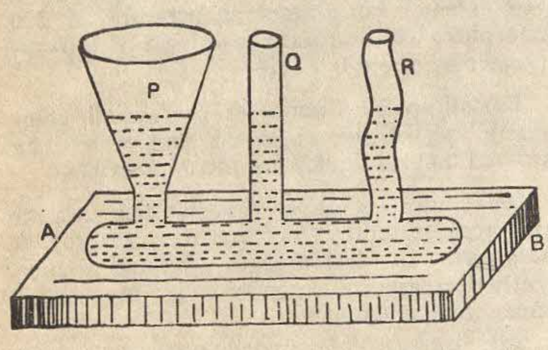


Fig. 2.6

A *spirit level* is constructed on the above property of the liquids.

The above property of the liquid also explains why is the surface of water in an undisturbed tumbler a perfect horizontal plane. is so because of the influence of the force gravity. We know that the earth pulls eve object towards its centre. The force of grav on all particles having the same mass and at a fixed distance from the centre of the earth, is the same. Thus all particles (or molecules) of water experience the same force and its surface would actually be the part of a sphere whose radius is equal to that of the earth (and whose centre coincides with the centre of the earth). Since the radius of the earth is very large (6400 km), the surface of water in the tumbler appears to be flat and horizontal. However, consider water contained in a vast natural vessel, the sea. The water surface in this case will also be a part of the sphere considered above.

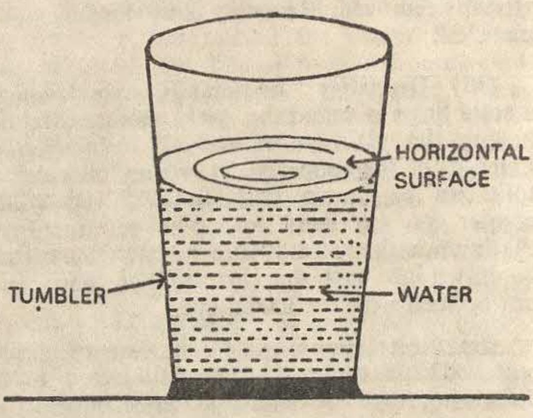


Fig. 2-7. Surface of water in a tumbler is horizontal

2.5. LIQUID SURFACE AS A STRETCHED MEMBRANE (Surface Tension) :

Try the following experiments which seem to show that the surface of liquids is covered by an elastic skin.

Requirement. Water trough, razor blade, needle, a tumbler, small pebbles or nails, brush, test-tube, large cylinder of gas, jar, sand, some kerosene, copper wire, thread and soap solution.

Experiment (*a*). Place a needle or razor blade on blotting or filter paper. Carefully lower this on the surface of the water contained in a trough. Note what happens. After some time put a drop of kerosene near the needle and watch what happens.

In the first case, you will notice that the blotting paper sinks leaving the needle or blade to float on the surface of the water.

In the second case, as soon as the kerosene is introduced, the needle sinks.

What has made the needle or the blade float ? Surely what makes a cork float in water is not the same as what makes the needle float ; for if the cork is pushed below the surface of the water it comes up again, but if the needle is treated the same way it sinks.

Experiment (*b*). Take a small test-tube, and put in it sufficient sand to make it float upright in water, contained in a large cylinder or gas jar. Continue to add sand carefully and watch the test-tube sink gradually in the water (Fig. 2.8). When the edge of the test-tube is at the same level as the water surface, continue to add more sand and watch what happens.

Now pour some kerosene on the surface of the water and watch the result.

You will notice that the test-tube still floats even when the edge of the test-tube is well below the surface of the water [Fig. 2.8 (*c*)].

When kerosene is poured on the water the test-tube sinks immediately.

What has made the test-tube float when it is completely below the surface of the water and it should normally sink ? Why does it sink when kerosene is poured on the water ?

Experiment (*c*). Fill a tumbler to the brim with water. Now start putting small nails or sand inside the water so that the water is displaced upwards.

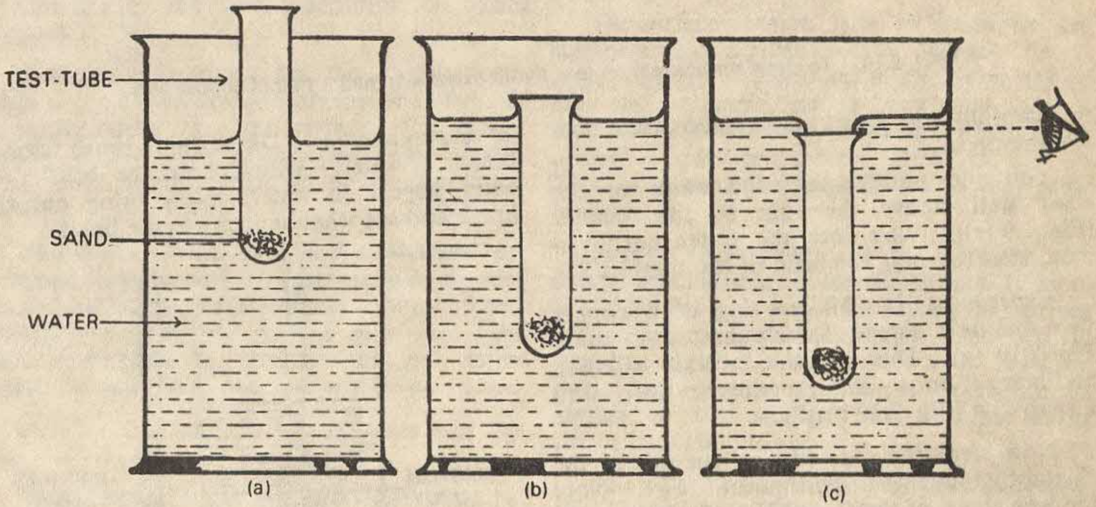


Fig. 2.8. To show surface tension in a liquid using test-tubes of sand.

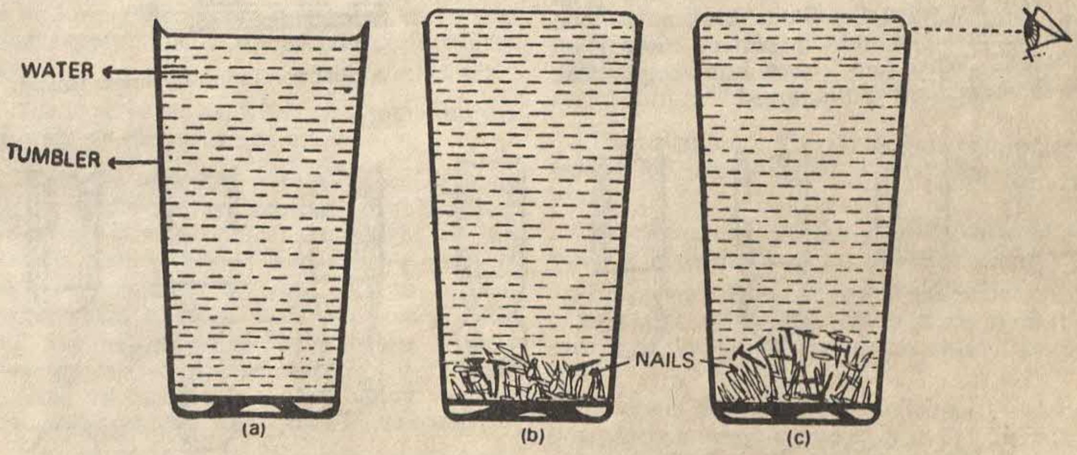


Fig. 2.9. To show surface tension in a liquid using small nails.

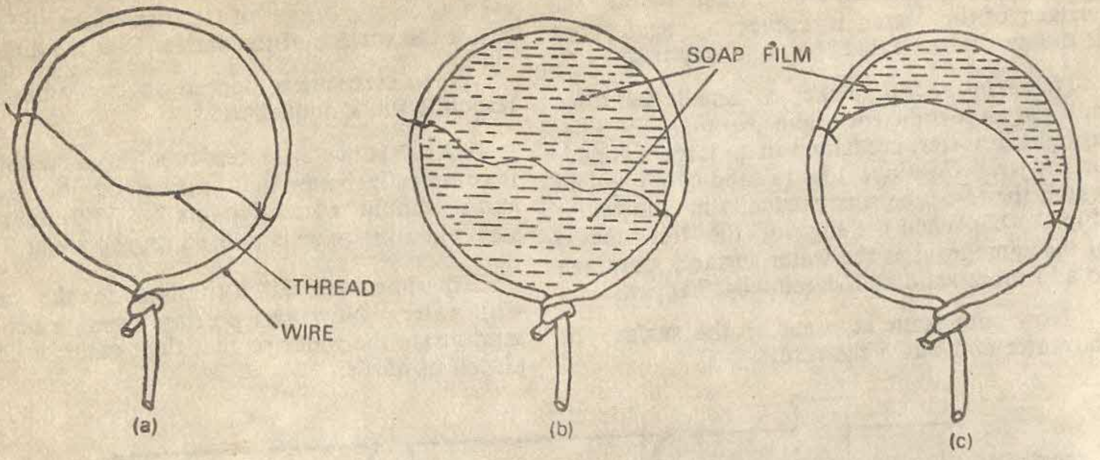


Fig. 2.10. To show surface tension in a liquid using soap and a ring of copper wire.

Carefully add a few nails more and note what happens.

You will observe that the water surface rises well above the edge of the tumbler [Fig. 2.9 (*c*)]. Why does the water not overflow, after reaching the brim of the tumbler ?

Experiment (*d*). Make a ring of a copper wire and tie a thread loosely across it as in Fig. 2.10 (*a*). Dip it inside a soap solution and bring it out so that the ring is filled with a soap film [Fig. 2.10 (*b*)].

Now break the soap film on one side of the thread by touching it with a hot wire. Note the new shape of the thread [Fig. 2.10 (*c*)].

You will observe that the thread first lies loosely in any position in the soap film [Fig. 2.10 (*b*)], but when the film is broken on one side the thread assumes a perfect curve [Fig. 2.10 (*c*)]. What could have been responsible for the new shape of the thread ?

Experiment (*e*). Dip a paint brush into a beaker of water. Watch how the bristles or hairs appear in water. Now bring out the brush and see what happens to the bristles.

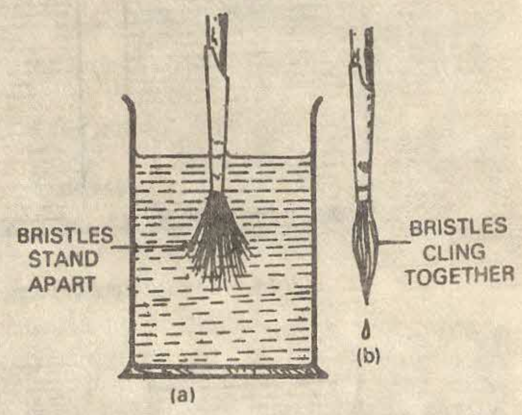


Fig 2.11. A paint brush showing surface tension.

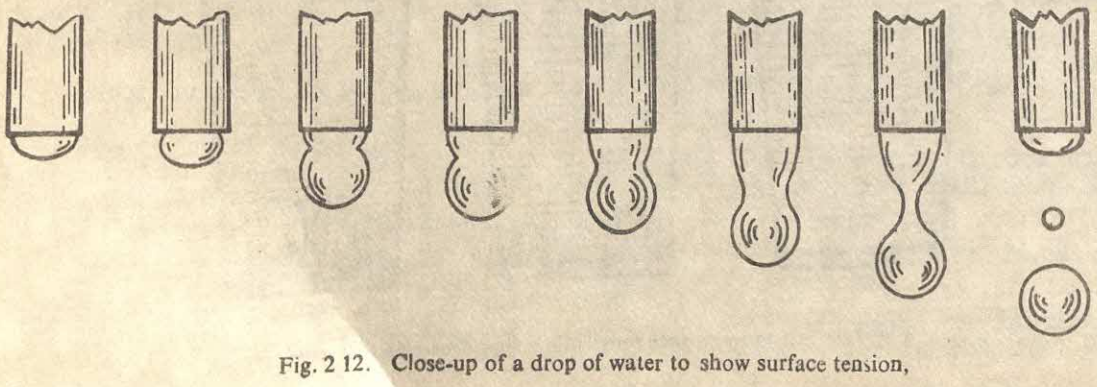


Fig. 2 12. Close-up of a drop of water to show surface tension, You will notice that when the brush is in water the bristles stand apart, but when taken out of the water they cling together [Fig. 2.11 (*a*) and (*b*)]. How can this be explained ?

Experiment (*f*). Turn on a water tap so that water comes out in tiny little drops. Watch how each drop grows and how it eventually drops.

The growth of the water drop (Fig. 2.12) looks as if the mouth is covered with an elastic skin which stretches when more and more water gets into it until it can hold no more and it bursts.

Can this be the true description of what happens ?

General Explanation. All the observations made in the above experiments can be explained by saying briefly *that the surface of a liquid behaves as if it were a stretched, thin, elastic skin, which always tends to be as small as possible.*

The force which causes the surface of a liquid to behave like a stretched elastic skin is called surface tension. Some force is needed to break the surface film, and this force is different for different liquids. It is greater in water than in oil or in soap solutions.

Now let us take the experiments one by one :

In (*a*) the surface of the water seems to be stretched skin, bending under the weight of the needle or razor blade. The needle sinks when an oil is poured on the water, because the oil lowers the surface tension of the water which supports the needle and the surface gives way.

The experiment explains way some insects can walk on the surface of water.

In (*b*) the tube does not sink because it is held up by the surface tension of the water. The surface stretches under the weight of the test-tube, getting thinner and thinner until it breaks, that is, until the force due to surface tension which supports it is overcome. This does not happen until the test-tube is well below the surface of the water. Oil reduces the force of surface tension holding up the test-tube, and so the latter sinks immediately.

In (*c*) as the nails are put into the water, the surface of the water stretches, because the water is displaced upwards. Thus, the surface behaves as if it were an elastic skin. A drop of oil will make the surface break earlier, as the surface tension is decreased, *i.e.*, the skin becomes less elastic.

In (*d*) the thread first lies in any position in the soap film because the thread is being pulled on both sides by equal forces of surface tension. But when one side of the film is broken the surface tension acts only on one side of the thread and, as the water tries to make its surface as small as possible, it pulls the thread in such a way as to form a perfect curve.

The surface tension tries to minimise the surface area of a given mass of liquid. *For a given volume, a sphere has a minimum surface area and a circle has a maximum surface area and hence all free drops of liquid try to assume a spherical sphere.* However, due to force of gravity the drops flatten as they grow in size.

In (*e*) it is clear that it is the exposed surface of a liquid that possesses surface tension. While the brush is *inside* the liquid, no surface tension acts on the bristles which therefore do not cling together. But as soon as it is taken out of the water the water tends to reduce its surface to the smallest area and so makes the bristles cling together.

In (*f*) the true position has been described, that is, the outer surface of the drop seems to be an elastic skin containing water and stretching as more and more water gets into it.

Another very interesting experiment you might wish to perform is described below. It illustrates the fact that the surface tension of soap solution is less than that of water.

Experiment : *To show that the surface tension of soap solution is less than that of water.*

Requirements : A fairly wide trough of water, a match-stick or toy boat and soap.

Procedure. Rub one end of the match-stick or toy boat with soap. Now place it on the surface of the liquid and watch what happens to it.

You will find that the match-stick or toy boat starts moving immediately in one direction only and that is in such a way that the end that is not rubbed with soap is always in front

(Fig. 2.13). Any attempt to make it move in the opposite direction will fail.

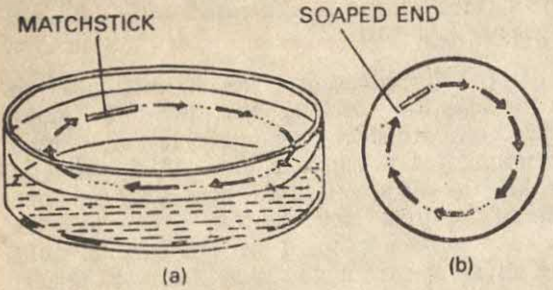


Fig. 2.13. The surface tension of soap solution is less than that of water.

Explanation. The soap at the end of the stick immediately dissolves in water, thereby lowering the surface tension at that end of the match-stick. The surface tension at the other end being now greater pulls the match-stick and makes it move in that direction until the whole surface is covered with soap solution.

Thus due to contamination, the surface tension of a liquid changes. In fact it decreases. Surface tension of a liquid also changes with temperature. It decreases with the rise in temperature.

Umbrellas, raincoats, tents and canvas. If you hold an umbrella or a raincoat up against the light you will notice that it is porous, that is, there are tiny holes in it. In spite of this, when rain falls, the water does not pass through the holes or pores. This is because the surface tension of the water prevents it from passing through the fabric unless the inside is touched. Touching the inside of the material breaks the surface of the water on the outside. The nature of the fibre of the material also plays some part.

Rise of liquids in narrow tubes : capillarity

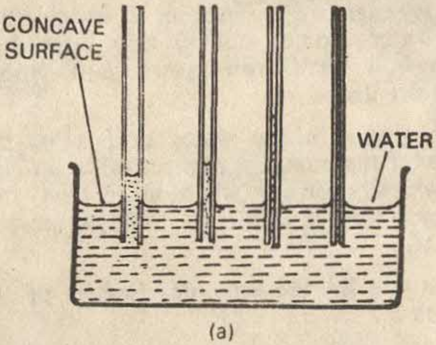
Try the following experiment.

Experiment. *To study the rise or fall of liquids in capillary tubes.*

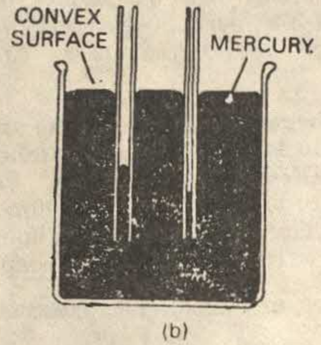
Requirements. Four 15 cm long narrow tubes (capillary tubes) of different bores ; a trough of water, coloured with blue or red ink and mercury.

Procedure. Stand the four narrow tubes upright in water and note the levels of the water inside them.

Then mount two capillary tubes upright in a beaker containing mercury and note the levels of mercury inside them.



(*a*) Water rises in the capillary tubes.



(*b*) Mercury falls in the capillary tubes

Fig. 2.14. Capillarity

You will notice that the water rises in each tube, but to different levels. It rises higher in narrower tubes than in the wider ones (Fig. 2.14).

The level of the mercury falls inside the tube. The narrower the tube, the lower it falls.

Explanation. The property possessed by a liquid to rise or fall in a narrow tube is called **capillarity.** All liquids that 'wet' their containers : *e.g.*, water, palm oil, alcohol and so on, will rise in a capillary tube, but liquids such as mercury and molten wax which do not 'wet their containers will fall inside it.

The rise or fall in level depends directly upon the surface tension of the liquid and inversely on the diameter of the capillary tube.

When water is poured out of a beaker and the beaker is thoroughly shaken to get rid of the water some drops still remain stuck to its sides. This means that water 'wets' its container. Mercury would not stick to the beaker, *i.e.*, it does not wet its container.

Capillarity explains the following observations :

1. Why ink spreads itself over a blotter or oil over a piece of cloth. This is because of the presence between the fibres of a number of narrow tubes or pores through which the liquid 'rises'.

2. Why oil will rise up the wick of a lamp. Again this is because of the narrow tubes in the fibres of the cotton making up the wick.

3. Why sap from the soil rises up plants. This is explained by capillary attraction, *i e.* rise of liquid in the narrow tubes in the tissues of the plant.

4. How ink gets to the tip of the nib of a fountain pen. It rises through the tiny space between the tongue and the nib of the pen.

2.6. ARCHIMEDES' PRINCIPLE

Dip a small bucket in a vessel containing water. Continue to push it in until it is completely inside. Then dip your hand into the water and try to bring out the bucket now full of water from the vessel. What do you feel ?

When trying to push the bucket into the water you will feel there is something pushing it back and preventing it from going into the water. Also as you bring the bucket out of the water, it first appears light while still in water, but as it comes out of the water it starts getting heavier and heavier. This something which hinders you in the first instance and helps you in the second is a force known as the **upthrust** on the bucket, and it always acts when a body is dipped in a liquid.

To show that upthrust also exists in air (or a gas), fill a toy balloon with a light gas (hydrogen or helium) and tie it securely with a long string which you can hold in your hand. Holding the string, let go of the balloon. Does it go up or down ? Now, let go the string too. What happens ? Try to explain this.

This and other similar illustrations seem to suggest that there is some upward force exerted by the fluid (liquid or a gas) on anything dipped into it. This upward force has been earlier referred to as upthrust and this behaviour of a fluid is referred to as its *buoyancy.*

Archimedes made a further study of the upthrust and discovered a principle. This important principle known as the *Principle of Archimedes* is said to have been discovered by Archimedes under very interesting circumstances. Hiero II, the king of Syracuse, ordered a jeweller to make a gold crown. When the crown was delivered, the king suspected it to be of impure gold. The king asked Archimedes to find out the percentage of pure gold. While thinking over the matter one day during his bath in a tank, he experienced that his body was being pushed up as if his weight has decreased. This experience of buoyancy excited him so much that, he came out of the bath undressed and shouted out "*Eureka, Eureka*" which in Greek means "I have found it."

Archimedes (287—212 B.C.) discovered that *a body, when fully or partly immersed in a fluid (liquid or gas) loses weight equal to the weight of the fluid (liquid or gas) displaced by its immersed part.* This is known as **Archimedes' Principle** and it has very wide applications. It can also be stated as follows :

When a body is fully or partly immersed in a fluid (liquid or gas), it experiences an upthrust equal to the weight of the fluid (liquid or gas) displaced by its immersed part.

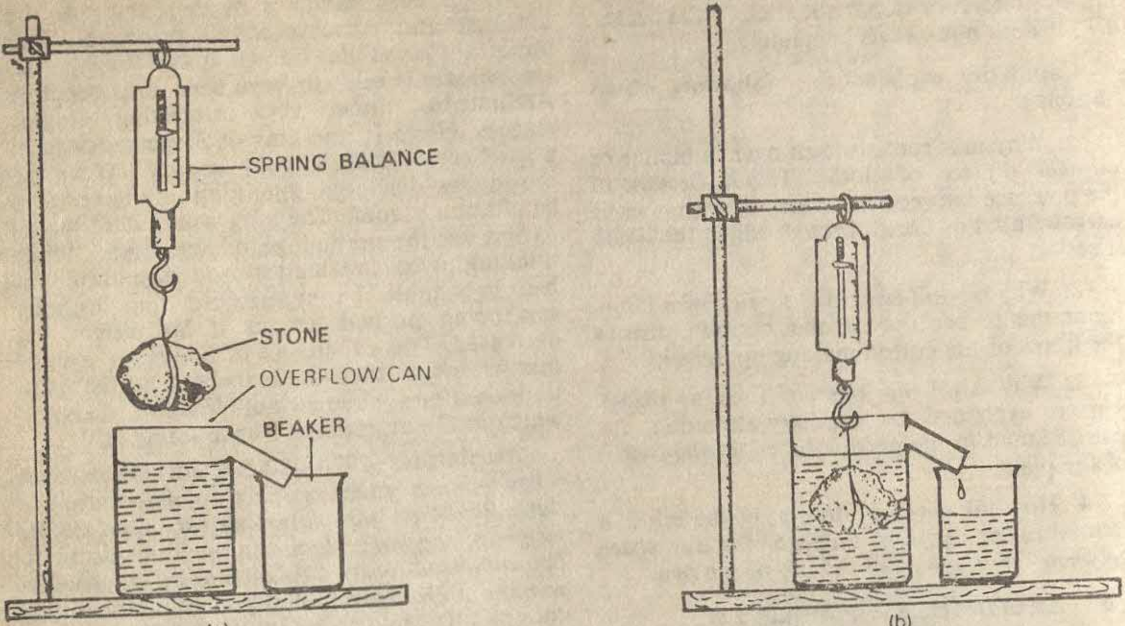
Experimental Verification of Archimedes' Principle

Requirements. Retort stand and clamp, spring balance stone, thread, overflow can beaker, lever balance or chemical balance and water.

Procedure. First weigh the stone by hanging it in air from a spring balance. Record the weight. Fill the can to the point of overflowing and place a clean, dry beaker which has been previously weighed, below the overflow tube. Now lower the stone, still hanging from the spring balance, into the can (Fig. 2.15) until it is fully immersed and collect the overflowing water in the beaker. Record the new weight of the stone as shown by the spring balance Also weigh the beaker again on the balance and deduct the weight of the displaced water.

Repeat the experiment twice and record our results.

If you are careful over the experiment you will find that the loss in the weight of the stone when dipped inside the water (*i e.*, the upthrust of the water on it) is equal to the weight of the



(a) (b)

Fig. 2.15. Testing the truth of Archimedes' Principle

displaced water. This confirms Archimedes' Principle as stated above.

The Principle of Archimedes is true for both liquids and gases.

Again, even though in the above experiment the stone has been fully immersed, you will get the same result if the stone has been partially immersed in the water. Try the experiment with the stone partially immersed in the water.

Use of Archimedes' Principle to Determine Densities of Solids

We can determine densities of solids by using Archimedes' Principle. Suppose we first weigh the object on a spring balance in air. (A spring balance measures weights (W) directly, not masses). Its weight is $W=Mg$ where M is the mass of the object and g is the acceleration due to gravity. We then submerge the object in water at the end of a supporting string, as in (Fig. 2.16) and measure its weight; which has now been reduced by the buoyant force (or upthrust) of the water. Hence, we have

$$W_w = W - F_B$$

or

$$F_B = W - W_w$$

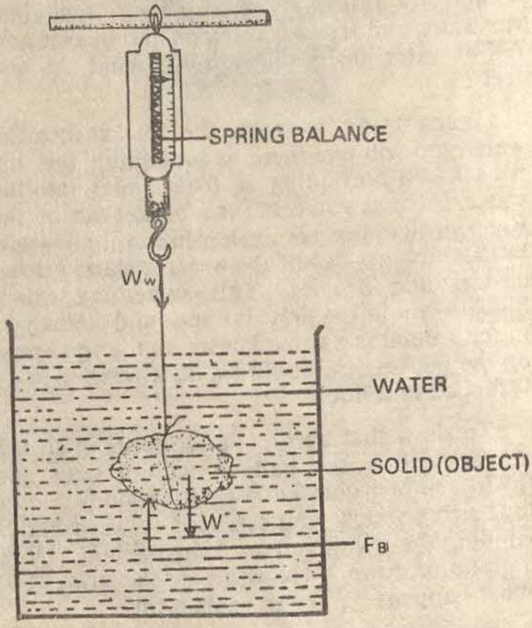


Fig 2.16

where W is its weight in air, W_w its weight in water and F_B is the buoyant force (or upthrust) of the water or the weight of water displaced by the object.

Now, by Archimedes' Principle,

$$F_B = V\rho_w g = W - W_w$$

where V is the volume of the given object and ρ_W is the density of water. V is also the volume of water displaced by the object.

$$\text{or} \quad V = \frac{W - W_w}{\rho_w g}$$

$$\text{Now} \quad V = \frac{M}{\rho}$$

where ρ is the density of the object.

$$\text{and so} \quad \frac{\rho}{M} = \frac{1}{V} = \frac{\rho_w g}{W - W_w}$$

$$\text{and} \quad \frac{\rho}{\rho_w} = \frac{Mg}{W - W_w} = \frac{W}{W - W_w}$$

$$\text{or} \quad \boxed{\rho = \frac{W}{(W - W_w)} \cdot \rho_w}$$

Hence the density of the solid object (ρ) can be founed from two weight measurements of the object—one in air, the other in water. For water, $\rho_w = 10^3$ kg/m^3. If the liquid other than water is used, the density of the object can still be found from the above equation, so long as the density of the liquid is known.

Again,

$$F_B = V\rho_w g = W - W_w$$

can be written as

$$W_w = W - V\rho_w g$$

$$\text{or} \quad W_w = V\rho g - V\rho_w g$$

$$\text{or} \quad \boxed{W_w = (\rho - \rho_w)\ Vg}$$

Notice that if the density of the solid (ρ) is **less** than that of water (ρ_w), then W_w will come out to be **negative**, *i.e.*, the effective weight of the body will become negative. In this case instead of going to the bottom, the body will rise to the surface and a part of it will come out of water. When will the body stop rising ? It will stop rising when its effective weight becomes **zero**. Let us see how it happens. As you would have noticed, a piece of wood or cork while floating on the surface of water is not fully immersed. Part of the body remains inside the water and rest outside it. Let V_1 be the volume of the body submerged in water so that the volume outside water is $(V - V_1)$. The loss of weight of the body will be equal to the weight of water displaced, which is $V_1\rho_w g$. Therefore, we have

$$W - W_w = V_1\rho_w g$$

$$\text{or} \quad W_w = W - V_1\rho_w g$$

$$\text{or} \quad W_w = V\rho g - V_1\rho_w g$$

$$\text{or} \quad W_w = (V\rho - V_1\rho_w)g$$

Since $\rho < \rho_w$ and $V > V_1$, we can find a value of V_1 (which is not yet fixed) such that $W_w = 0$ *i.e.*, the apparent weight of the body within water is zero.

$$\therefore \quad 0 = V\rho - V_1\rho_w$$

$$\text{or} \quad \boxed{\frac{V_1}{V} = \frac{\rho}{\rho_w}}$$

In fact this applies to any fluid (liquid or a gas). Thus, if we take a block of wood which has a graduated scale on one side and let it float in different liquids in turn, and note in each case the mark on the scale up to which it sinks, we can find the ratio of the densities of the different liquids.

2.7. PRESSURE

Pressure is defined as **the force per unit area between two surfaces in contact**. The materials in contact may be two solids, a liquid and a solid, or a gas and a liquid or a solid. To find the pressure (P), the total force (F) is divided by the area (A) over which it acts.

$$\text{Thus,} \quad \boxed{\text{Pressure} = \frac{\text{Force}}{\text{Area}}}$$

$$\text{or} \quad \boxed{P = \frac{F}{A}}$$

From this definition, it is obvious that pressure is measured in newton/metre^2 or N/m^2 or Kg m^{-1} s^{-2} in *SI* system. This unit is also known as **pascal** (symbol *Pa*).

Also, total force exerted by a given pressure is pressure times area on which it acts.

$$\boxed{F = PA}$$

or $$\boxed{\text{Force} = \text{Pressure} \times \text{Area}}$$

The force contributing to the pressure is that which is **normal** to the surface, not parallel to it.

From the definition of pressure it is clear

(*i*) pressure increases when the force increases or the area decreases.

(*ii*) pressure decreases when the force decreases or the area increases.

This explains why flat-footed camels can walk easily in sandy deserts whereas for us it is difficult to do the same inspite of the fact that the weight of a camel is much more than that of a human being. Heavy tractors can go through marshyland and muddy soil easily because their rear wheels have large area. Hand cutting and piercing tools like saws, needles and knives have sharp points or blades so that they exert more pressure with comparatively small applied force. If you take a balloon filled with air and press it between your palms, it may not burst till you press it very hard. Hewever, if you take a pin and prick the balloon with its sharp point, the balloon bursts with very little effort. Why ? Try to break a walnut in your hand without using a nutcracker. It is very difficult. Now try to break by taking two nuts and squeezing them together. What do you observe ? Can you give an explanation to this effect.

A common property of all fluids is that they exert pressure. If the force on every unit area of a surface is the **same**, the pressure is called **uniform pressure**. The pressure on the horizontal bottom of a trough containing water is uniform. If the force on every unit area of a surface is not the same, the pressure will vary from point to point. This would be the case if the trough containing water has **inclined bottom** instead of horizontal. In such a case we talk in terms of pressure at a point. If we imagine a very small area, dA surrounding a point, then the ratio $\frac{\text{Force on area } dA}{\text{area } dA}$ measures the pressure at that point.

LAWS OF LIQUID (FLUID) PRESSURE :

I Law : The pressure at a point inside a homogeneous liquid is the same in all directions.

In order to prove this law, let us imagine a small cavity surrounding a point in a homogeneous liquid. Evidently the liquid would have a tendency to rush in from all sides and fill it up. As soon as the cavity has been filled up, the liquid surrounding it is kept up in position due to the pressure exerted by the liquid in cavity. Since there is equilibrium, the pressure at that point in the cavity is the same in all directions.

II Law : *The pressure of a homogeneous liquid at all points in the same horizontal plane is the same.*

Let us consider two points A and B in the same horizontal plane inside a homogeneous liquid Fig (2.17). Join AB and imagine a small circular cylinder of liquid whose axis is AB. The only forces acting on this cylinder in the direction of the axis AB are the two pressures on the plane ends of the cylinder. All other forces acting on this cylinder are clearly perpendicular to AB and as such have no effect in the direction of AB.

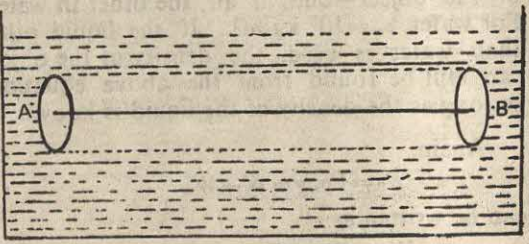


Fig 2.17.

For equilibrium, these two forces must be equal and opposite. Thus,

Pressure at $A \times$ area of the plane end A
$= $ Pressure at $B \times$ area of plane end B.

Since the area of the plane ends A and B of the cylinder are equal, therefore,

Pressure at $A =$ Pressure at B.

III Law : *Whenever pressure is applied on any part of a liquid (fluid) contained in a vessel, it is transmitted undiminished and equally in all directions.* This law was first enunciated by Pascal and is called *Pascal's Law*. It is also known as the *Principle of Transmissibility of Liquid Pressure*.

If you hold with both hands the inner tube of a bicycle tyre which has been filled with air and gently press part of it in your right hand, you will feel the effect on your left hand, showing that the slight pressure you have exerted with your right hand has been sent across through the air in the tube to your left hand. You would get the same effect if you filled the inner tube with water instead of air.

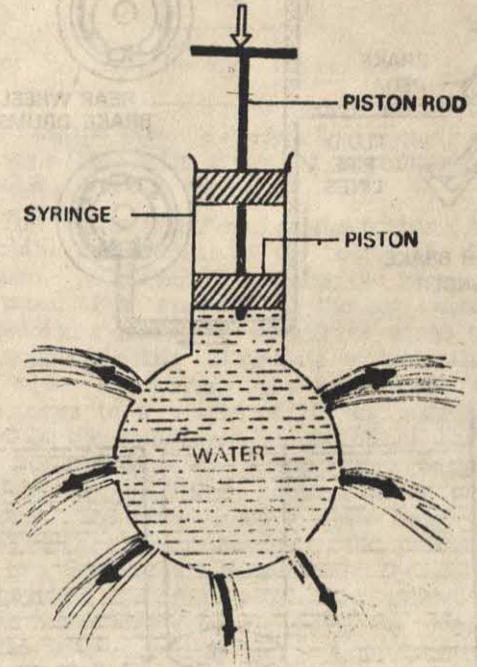


Fig. 2.18. Equal transmission of pressure in all directions

The equality of this pressure which is transmitted or sent across through air or water can be shown with a syringe of the form shown in Fig 2.18.

The bulb of the syringe has holes all round it pointing in different directions. A slight push of the piston causes jets of water to rush out from all the holes with **equal force,** showing that the slight pressure applied to the piston has been sent equally to all parts of the liquid.

The principle that a liquid transmits pressure equally in all directions has been used in making machines in which a small force is enlarged many times. Since pressure, no matter how small, is transmitted equally throughout the liquid, a small pressure can be made to act on a large area and so produce a large force there. For instance, in Fig 2.19, suppose the cylinder A has a cross-sectional area of $10\ cm^2$ and cylinder *B*, $50\ cm^2$. They are connected by a narrow cylinder and the whole apparatus is filled with a liquid, usually oil. If a force of 20 newton is applied on the piston of cylinder *A*, the pressure of $\frac{20}{10}=2$ newton/cm² which acts in *A* will be transmitted through the liquid to the piston of cylinder *B* to produce on it a force of $2\times50=100$ newton (Force = Pressure × area). This means piston of cylinder *B* can now raise a 100 newton load Thus a force of 20 *N* applied on the piston of cylinder *A* has been magnified five times to a force of 100 *N* in cylinder *B*. The ratio of the areas is 50 : 10, *i.e.*, 5 : 1. The ratio of the forces = 100 : 20, *i.e.*. 5 : 1. Thus you see that the force has been magnified in the ratio of the areas of the cross-section of the cylinders, *i.e.*, if you want to magnify a force ten times, the area of cross-section of the larger cylinder should be ten times the cross-section of the narrow cylinder. To make the force at *B* as big as possible, therefore, we have to make its cylinder a number of times as large as the cylinder *A*. This principle is applied in the working of the **hydraulic press** with which bags of cotton or wool, oil seeds, newly printed books and so on are pressed very firmly together by applying a little force. *Hydraulic brakes* in motor cars also work on the same principle. We apply a little force with our foot, and the pressure caused is transmitted through oil to act on a large area where pistons are made to move the brake shoes against the break drums Fig. 2.20.

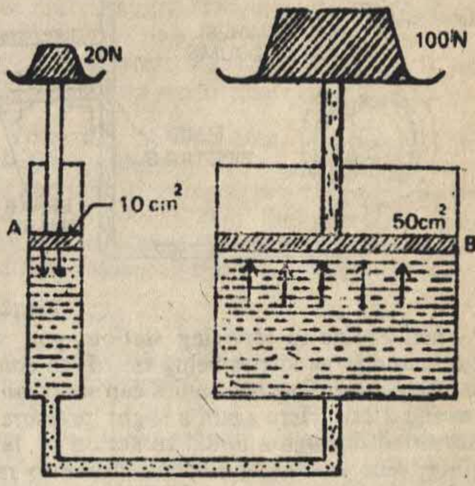
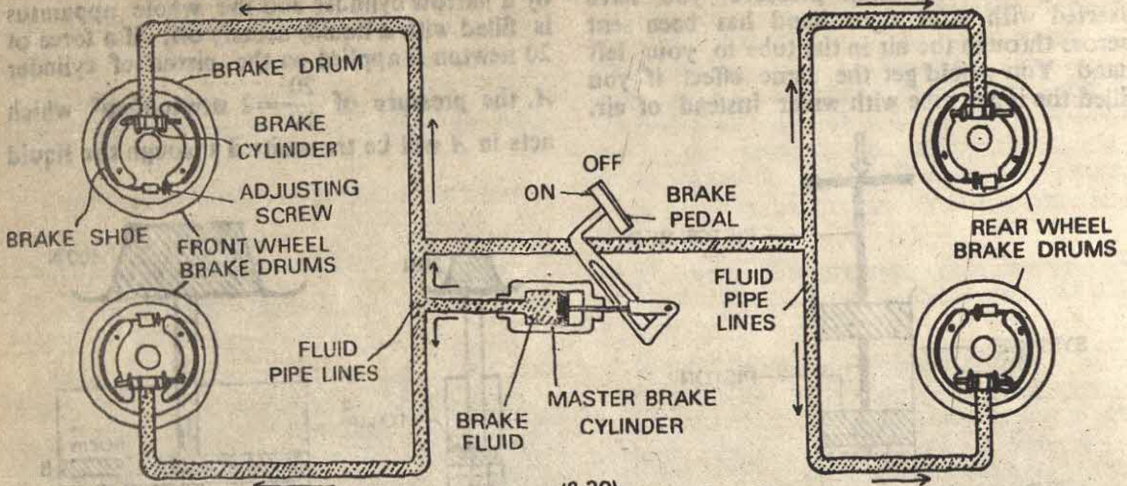


Fig. 2.19.



(2.20)

Fig. 2.20.

When you go to servicing stations you will see cars and large lorries being raised to convenient heights so that mechanics can work under them Fig 2.21. Here again a slight pressure is transmitted through a liquid to act on a large surface, thus producing sufficient force to raise up the vehicle. Such a machine is known as a *hydraulic lift*. Visit a car servicing station and examine how the hydraulic lift works.

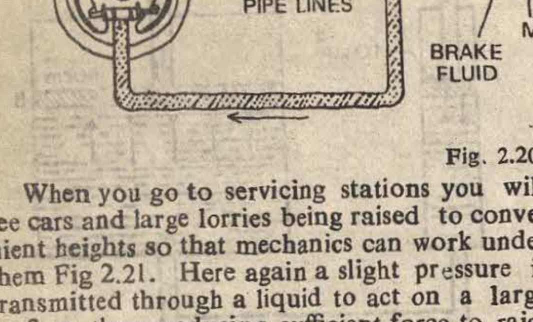


Fig. 2.21.

IV Law. *Pressure at any point at a depth 'h' in a liquid (fluid) of density 'ρ' is $h \rho g$ where g is the acceleration due to gravity at a place.*

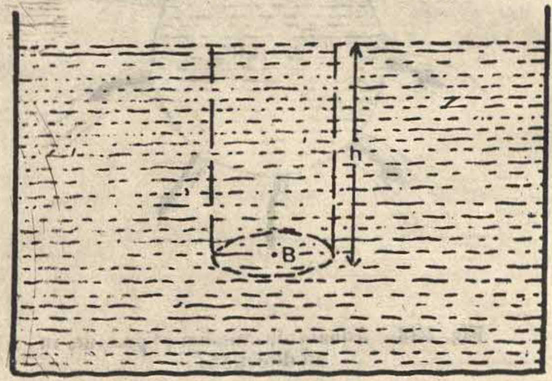


Fig. 2.22

Let us find the pressure at a point *B* inside a liquid of density ρ at rest. Let the depth of the point *B* be *'h'* below the free surface of the liquid (Fig. 2.22). Surrounding the point *B*, imagine a horizontal circle of area *A*. From every point of the boundary of this circular area *A*, draw vertical lines upto the free surface of the liquid. We have thus a circular cylinder of the area of cross-section *A* and height *h*. The force on the area *A* is equal to the weight of the liquid contained in this imaginary cylinder. Hence, total force on the area *A*

= weight of the liquid contained in the imaginary cylinder

= mass of the liquid × acceleration due to gravity

= Volume of the liquid × density of the liquid × acceleration due to gravity

= area of cross-section of the cylinder × height × density × acceleration due to gravity

$= A.h.\rho.g$

Since, $\text{Pressure} = \dfrac{\text{Force}}{\text{area}}$

$$\therefore \qquad P = \frac{A\,h\rho g}{A}$$

or $$\boxed{P = h\rho g}$$

Thus, the pressure inside a fluid (liquid) of density ρ (fluid being at rest) at a point at a depth h is equal to $h\rho g$.

This implies that $P \propto h$ *i.e.*, the pressure of a fluid is proportional to the height of the column. As the height increases, the pressure increases. For example, in the sea, water pressure at a depth of 1 m will be equal to the weight of nearly 10^3 kg mass of water on one square metre area. At a depth of 100 m, it increases to a weight of 10^5 kg mass of water on the same area. Most of us have heard of huge dams like Krishna Raja Sagar, Bhakra, and Hirakud constructed in our country. The construction of these dams is based on the above principle *i.e.*, the pressure due to a liquid at rest increases with the depth of the liquid. When huge dams are constructed with very high retaining walls, the depth of the water stored is great. Consequently, the pressure at the bottom of the dam is enormous and this high pressure is utilized to turn turbines producing large amounts of electric power.

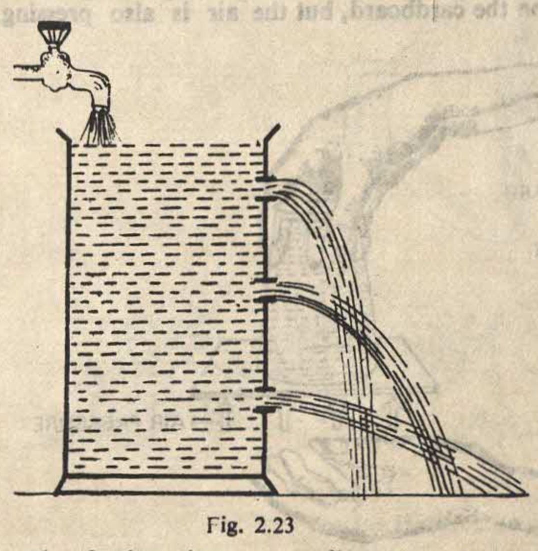


Fig. 2.23

The farther down you dive beneath the surface of water the greater is the weight of water acting upon you, and you would, therefore, expect that the pressure of the water would increase. This increase in pressure can be shown by the following experiment.

Take any fairly tall tin with holes made at three different heights. Fill tin can with water, taking care to cover the holes until the tin is filled. Now open the holes and watch how the water comes out of them (Fig. 2.23).

You will observe that water comes out with the greatest force through the bottom hole and with the least force through the top hole. This shows that the pressure inside water at the level of the lowest hole is greater than the pressure at the level of the top hole.

Air Pressure

We are surrounded everywhere by a layer of air which stretches for some kilometres above the surface of the earth. You have already learnt that air has weight (*i e*, **pull** of the earth on it), and you can imagine that this weight of air must be pressing upon us In fact, we can show by means of simple experiments that the air presses on us with some force and hence exerts a pressure.

Experiment 1. *Collapsing Tin Experiment.*

Requirements. An empty 5-litre engine oil tin or an empty 15 litre kerosene tin, water, bunsen burner.

Procedure: Pour some water into the tin can and boil it until all the air has been driven out and steam is occupying the whole space above the water in the tin [Fig. 2.24 (*a*)]. Now remove the burner and cork the tin very tightly. Pour cold water over the tin and watch what happens.

The tin will collapse immediately as if it is under a heavy weight [Fig. 2.24 (*b*)].

Explanation. When the water is poured over the tin the steam condenses, thereby leaving an empty space in the tin. The air presses on the tin from outside, and since there is nothing inside the tin to support this pressure, the tin collapses under the pressure of the air.

It has thus been shown that air exerts a pressure.

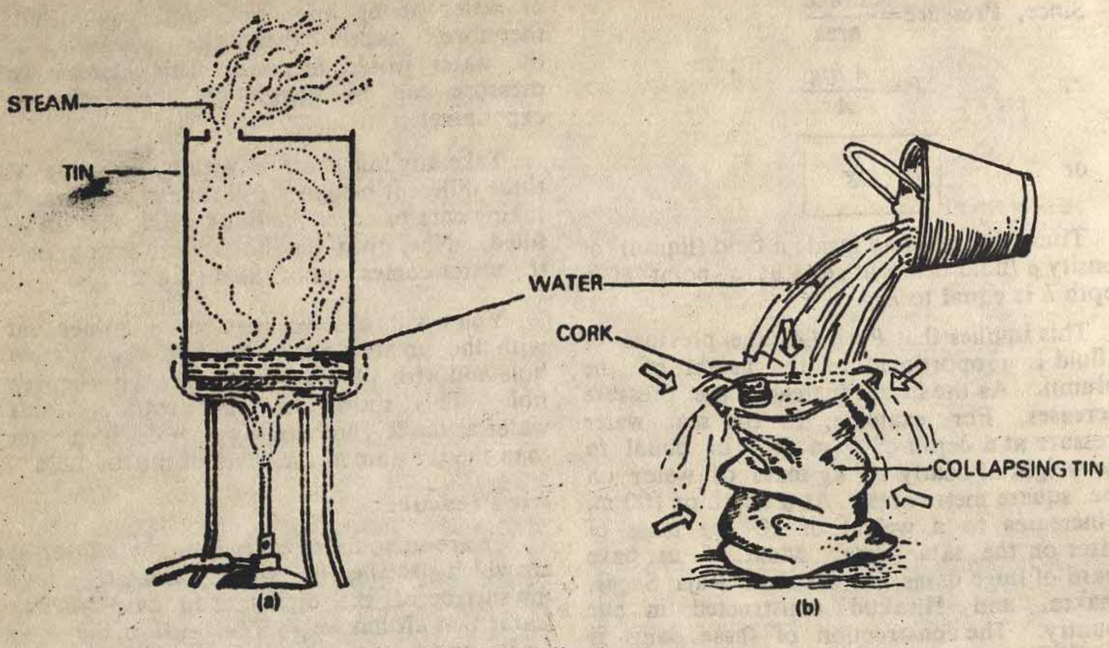


Fig. 2.24. The collapsing tin experiment

Experiment 2. *Tumbler and Cardboard Experiment.*

Requirements. A tumbler, cardboard, water.

Procedure. Fill the tumbler to the brim with water until the water runs over the edge. Place a piece of cardboard, a little larger than the tumbler, over the top and press it on tightly. Now turn the tumbler upside down over a sink (Fig. 2.25). Does the cardboard fall of ?

You will notice that the cardboard remains in position, even though it is not held there with the hand.

Explanation. The water is pressing down on the cardboard, but the air is also pressing

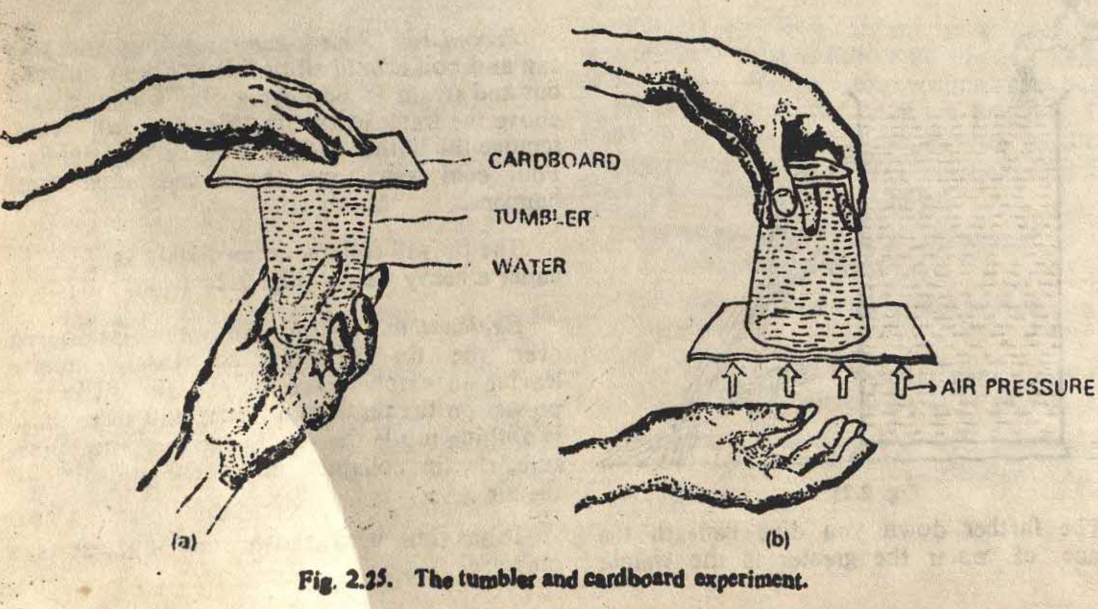


Fig. 2.25. The tumbler and cardboard experiment.

the cardboard upwards. The pressure of the water is not sufficient to overcome that of the air, and so the cardboard does not fall off. In fact, it will require a tumbler about 10·3 m long to contain water which will provide sufficient pressure to overcome that of air.

This experiment has again shown that air exerts a pressure.

Experiment 3. *The Magdeburg Hemispheres.*

Here is another experiment of historical importance :

The experiment was performed in 1654 by Otto von Guericke in the German town of Magdeburg. He made two hollow metal hemispheres which could fit tightly together [Fig. 2.26 (*a*)]. He first showed how easily the two halves could be separated. He then fitted them together to form a sphere, from which he withdrew as much air as possible using an air pump. It was found that the two hemispheres could no longer be separated. In fact, it took eight horses attached to each hemisphere to separate them ! [Fig. 2.26 (*b*)].

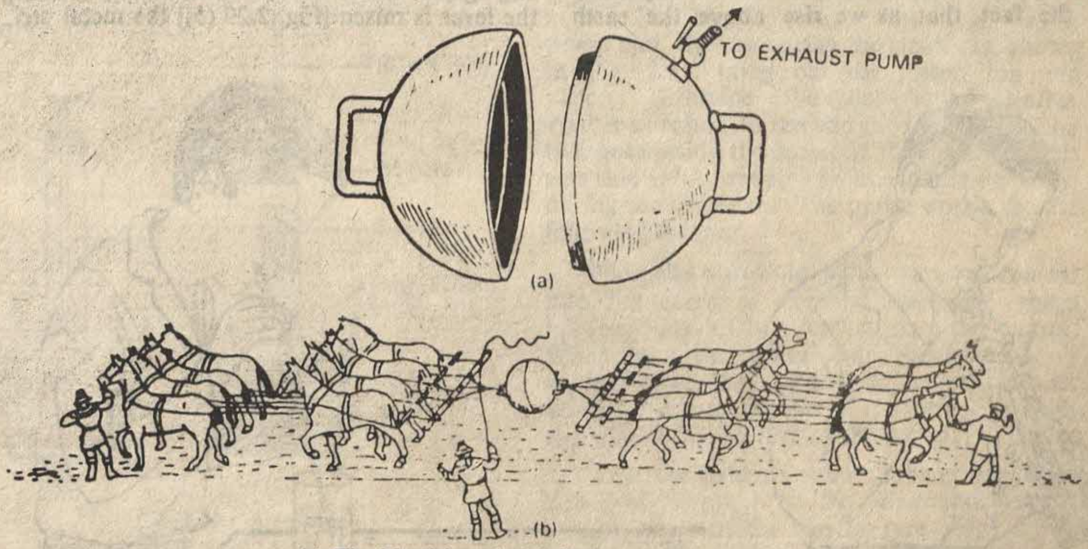
Explanation. When air had been drawn out of the sphere, the only force holding the two hemispheres together was due to the pressure of the air from outside. The fact that it required sixteen horses to separate the hemispheres shows that the pressure of the air is great.

The three experiments described above have shown you that air exerts a pressure. The next obvious question is : How great is this pressure ?

The pressure of the atmosphere :

The earth's surface is surrounded by a thick layer of air called the **atmosphere**. Air is a mixture of gases containing about $\frac{4}{5}$th by volume of nitrogen, about $\frac{1}{5}$th oxygen and a small percentage of carbon-dioxide, together with very small quantities of neon, argon, krypton, Xenon, helium, hydrogen, ozone and water vapour. The atmosphere is most dense at ground or sea-level and extends to a height of about eighty to several hundred kilometres, an approximate figure. The higher one goes the less dense is the air, since there is then less weight of air above to compress it. Above the earth's atmosphere in interstellar space, there is practically a vacuum

The pressure exerted by the atmospheric air at any point is equal to the weight of air contained in a column of *unit cross-sectional area* and extending upto the top of the atmosphere. This is called **atmospheric pressure**. Often it is expressed in terms of the height of an equivalent mercury column (in a barometer).



(*a*) The Magdeburg hemispheres.

(*b*) Sixteen horses trying to separate the hemispheres.

Fig. 2.26. Otto von Guericke' experiment.

Under normal conditions the atmosphere at sea level exerts a pressure equivalent to pressure due to mercury column of height 76 cm or 760 mm. This is called **one atmosphere** (atm).

Since, $h = 76 \text{ cm} = 0{\cdot}76 \text{ m}$

Density of mercury $= \rho = 13600 \text{ kg/m}^3$

Acceleration due to gravity $= g = 9{\cdot}8 \text{ m/s}^2$

$\therefore$ One atmosphere $= h\rho g$

One atm $= 0{\cdot}76 \times 13600 \times 9{\cdot}8 \text{ N/m}^2$

$= 1{\cdot}013 \times 10^5 \text{ N/m}^2 = 101{\cdot}3 \text{ k Pa}$

($\because$ $1 \text{N}/m^2 = 1$ pascal)

$1{\cdot}000 \times 10^5 \text{ N/m}^2$ is called one **bar**. A thousandth of a bar is a **millibar** (mb). Normal atmospheric pressure is 1013 mb, just over 1 bar.

1 millibar $= 10^2 \text{ N/m}^2$

It may puzzle a layman that if air exerts a pressure of $1{\cdot}013 \times 10^5 \text{ N/m}^2$, why he does not feel it. It is due to the fact that a fluid transmits pressure equally in all directions. The pressure of air inside our lungs or tissues etc. balances the pressure due to the air outside. When the outside pressure is less than that inside, we begin to feel uncomfortable. Men who fly at very great heights have not only experienced difficulty in breathing but also have suffered from bleeding at the nose. They may also have a popping sensation in their ears as the aeroplane rises in the air. This is explained by the fact that as we rise above the earth the air pressure becomes less and the pressure of the air inside our head, being now greater than the pressure outside, pushes air outwards against our eardrums.

Some Common devices depending on air pressure

1. *Drinking through straws and using the pipette.* When you use a straw to drink your lemonade, do you realise how atmospheric pressure makes it very easy for you? It is not simply a matter of sucking the liquid through the straw into your mouth (Fig. 2.27). In actual fact, what you are doing is sucking out the air from the straw, while atmospheric pressure acting on the surface of the liquid in the bottle forces the liquid into the straw. A similar explanation can be given for the use of the pipette (Fig. 2.28).

2. *Breathing.* When we 'breathe in' we are not actually sucking in air. The muscles raise the ribs, enlarging the chest cavity, and this has the effect of lowering the pressure inside the lungs. The atmospheric pressure outside then forces air into them. 'Breathing out' is the reverse process.

3. *Filling a fountain pen with ink.* The fountain pen of the type shown in Fig. 2.29 works in the same way as the straw and the pipette. The pen consists of a long rubber bag against which rests a metal strip. When the lever is raised [Fig. 2.29 (*b*)] the metal strip

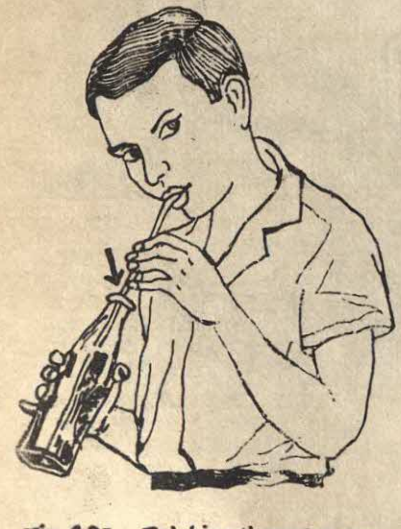


Fig. 2.27. Drinking through a straw.

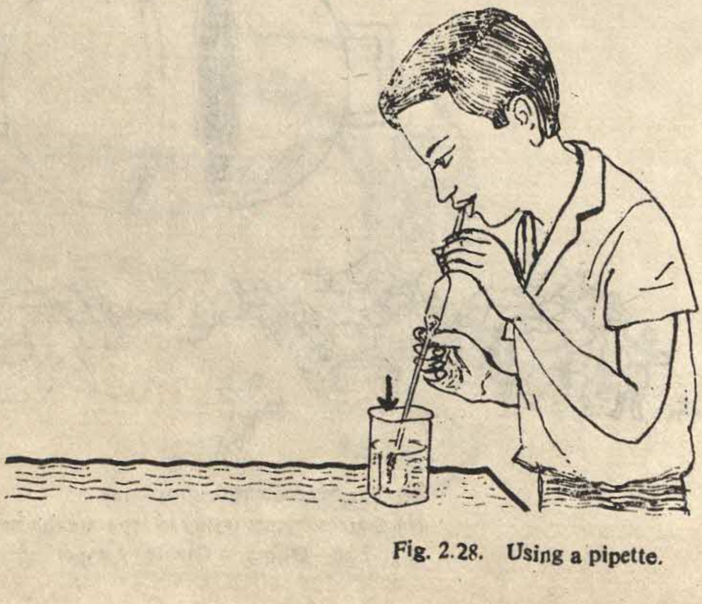
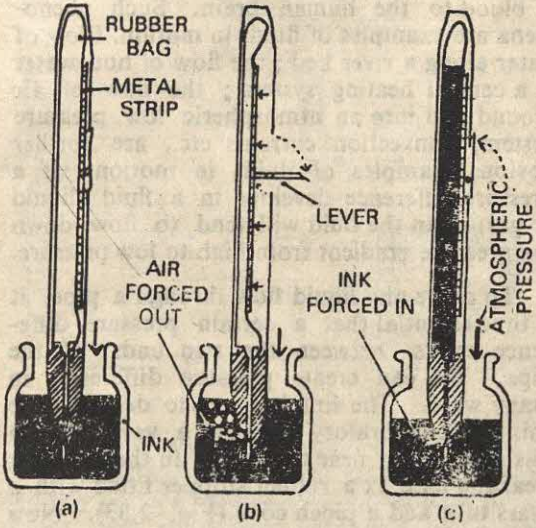


Fig. 2.28. Using a pipette.

is pressed against the rubber bag, driving the air out of it. When the lever is released the bag opens out and, because air has been forced out of it, pressure inside it is lowered. Atmospheric pressure acting on the ink in the bottle, being now greater than the pressure inside the bag, forces the ink into the bag.



(2.29)

Fig. 2.29. Filling a fountain pen.

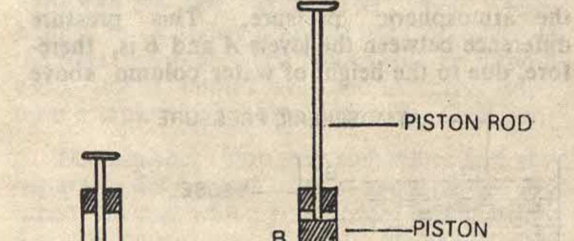


Fig. 2.30. A syringe.

4. *The syringe.* This is an instrument used for injection purposes. It consists of a barrel fitted with a piston and a rod. The piston fits the barrel exactly, and can be moved up and down with the help of the rod. When the piston is in position A (Fig. 2.30), dipping into the liquid to be used, the air has been driven out of the barrel. When it is moved up to position B the space below the piston is more or less a vacuum. The pressure of the atmosphere acting on the surface of liquid forces the injection liquid into the barrel.

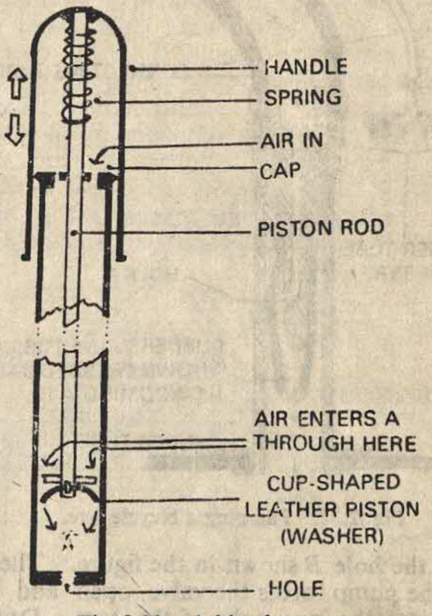


Fig. 2.31. A bicycle pump.

5. *The bicycle pump.* Obtain a bicycle pump and, by unscrewing the small cap shown in Fig. 2.31, bring out the piston rod and piston. Examine the cup-shaped leather washer attached to the end of the piston rod that goes inside the barrel of the pump. This acts as a valve, opening in one direction only, during the upstroke. The pump works in the following manner.

When the piston is pulled up, air passes into the barrel *A* through the tiny space between the leather washer and the barrel. When the piston comes down, the valve closes so that the air that has entered cannot find its way out ; it is forced out of the pump through the hole at the bottom of the barrel.

To use the pump, a rubber tube connects the hole *A* of the pump to the valve attached to the inner tube of the bicycle tyre (Fig 2.32). This valve also opens in one direction only, to admit air into the inner tube. The valve consists of a tight-fitting rubber tube which

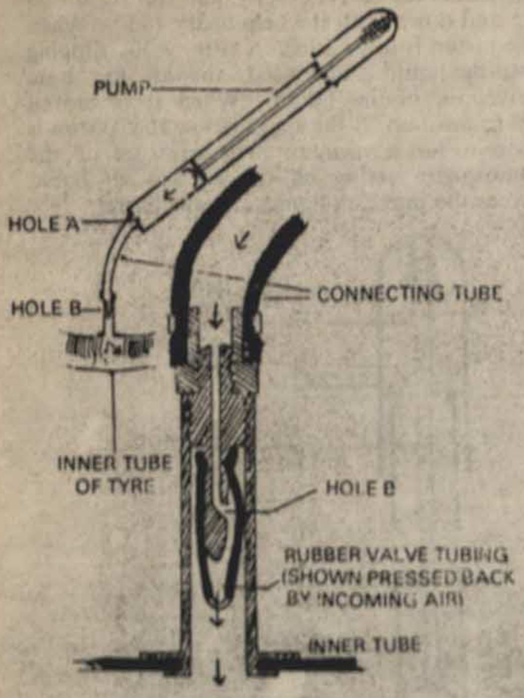


Fig. 2.32. Pumping a bicycle tyre.

covers the hole *B* shown in the figure. The air from the pump forces the valve open and air passes into the inner tube of the tyre. During the upstroke of the pump the rubber valve covers the hole so firmly that no air can go back. The process is repeated until the tyre is fully inflated.

2.8. FLOW OF FLUIDS

Some liquids such as water and kerosene flow very easily from one vessel into another and are said to be *mobile*. Other liquids such as glycerine, coal tar, soups etc., flow much more slowly and are said to be *viscous*. The property of a liquid (fluid) which determines its rate of flow (*i.e.*, flow of liquid in one second) is called *viscosity*. This viscosity of a liquid is due to the friction that exists between the liquid and its container and also between the different layers of one liquid. The viscosity of liquids is very important in selecting oils for the lubrication of machines. You already know why machines should be lubricated. Different parts of machines require oils of different viscosities for lubrication. Lighter machines require mobile oils while heavier ones ight require more viscous oils.

We depend on the flow of fluids throughout much of our lives. Oil and natural gas are pumped hundreds of kilometres through pipes to satisfy heating and transportation needs. Gigantic pipes bring fresh drinking water from mountain reservoirs to large cities. Deadly strokes occur when blood clots cut off the flow of blood to the human brain. Such phenomena are examples of fluids in motion. Flow of water along a river bed ; the flow of hot water in a central heating system ; the flow of air around and into an atmospheric low pressure system, convection currents etc., are further obvious examples of fluids in motion. If a pressure difference develops in a fluid (liquid or gas), then the fluid will tend to flow down the pressure gradient from high to low pressure.

To make any liquid flow through a pipe, it is thus essential that a certain pressure difference exists between the two ends of the pipe. We can create pressure difference in many ways. The simplest way to demonstrate this in the laboratory is to use a vessel which has an opening near the base. In the opening near the base fix a rubber stopper fitted with a glass tube and a pinch cock (Fig. 2.33). Now if we fill water in this vessel, the pressure at level *A* will be the atmospheric pressure plus that due to the height of water colum above *A*, whereas the pressure at the level *B* will only be the atmospheric pressure. This pressure difference between the levels *A* and *B* is, therefore, due to the height of water column above *A*. If you observe the rate of flow of water (*i.e.*, the volume of water that comes out in one second), it will decrease with time because as the level of water falls, the pressure difference between *A* and *B* decreases. It is imortant to note that the pressure at *A depends only on the height of the water column above and not on total volume of water*. For example pressure difference between levels *C* and *D* in

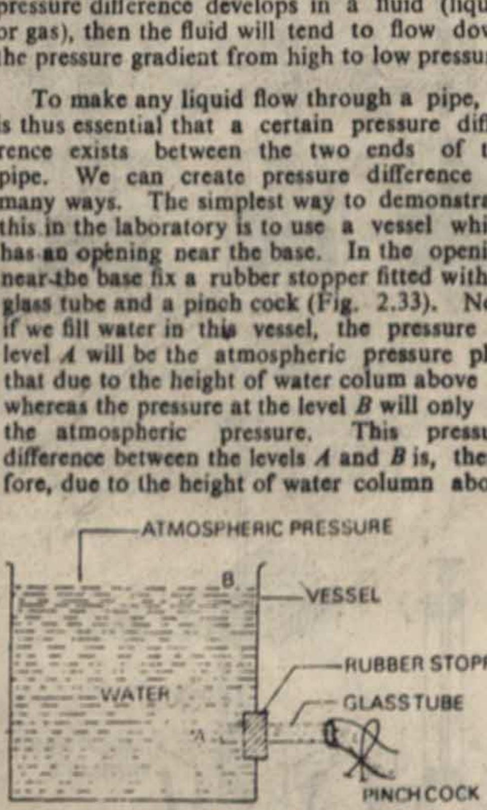


Fig. 2.33

[(Fig. 2.34 (*a*) and (*b*)] is the same even though they are differently connected and have different volumes of water.

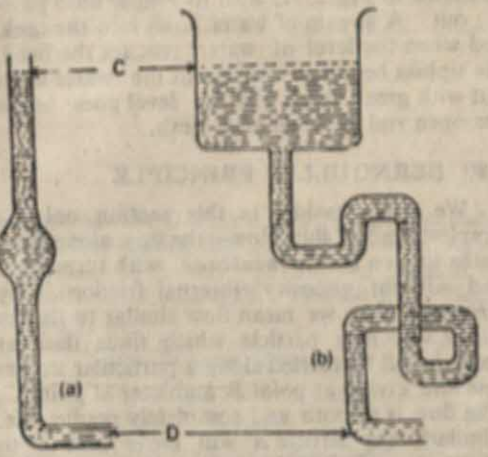


Fig. 2.34

The water supply of some towns is drawn from a reservoir (Fig. 2.35) which is higher than any part of the town itself. In fact water from a river or a lake is filtered and then pumped into the tank built on the top of a hill or on a tower. Since water finds its own level, it can rise through the water pipes in the houses to the taps. If, however, some houses happen to be higher than the level of water in the reservoir, then such houses will be without water unless pumps are used to force water upto a tank which stores it there for their use.

The siphon. You may sometimes find you require to draw water from a vessel which you cannot lift and which you cannot easily reach. Again someone may want to transfer petrol from a friend's car into his car. How can you help ? First try the following experiment.

Requirements. Two buckets of water, one on a table and the other on the ground ; a fairly long rubber tube.

Procedure. Dip one end of the rubber tube into the water in the bucket standing on the table. Let the other end hang freely pointing into the other bucket (Fig. 2.36). Does the water come out ? Now put the free end of the rubber tube in your mouth and suck out the air from the tube. Then let it hang freely again pointing into the empty bucket. Does water come out now ? Gradually change the depths of the open mouth below the level of water in the bucket and watch the rate at which water comes out at each level.

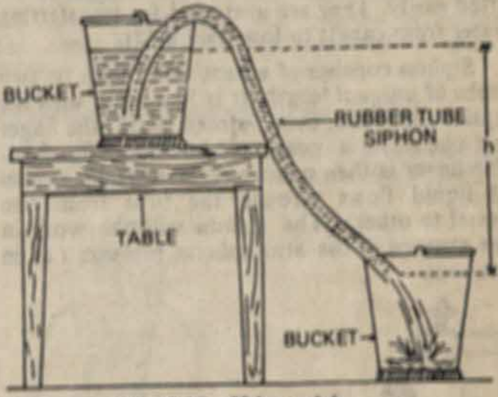


Fig. 2.36. Using a siphon.

You will notice that no water flows through the tube until the air has been sucked out. The farther down the open mouth of the tube goes, the greater the rate of flow of the water. Also,

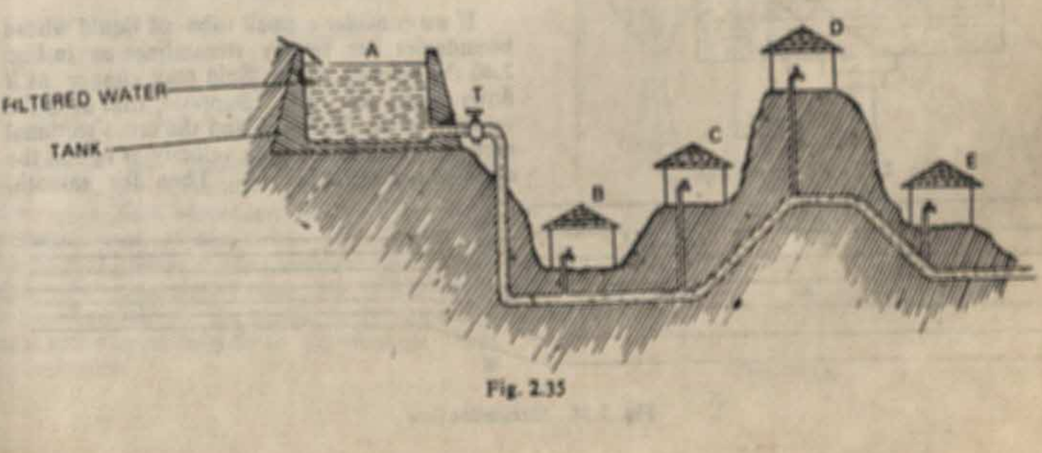


Fig. 2.35

when the mouth of the tube is raised above the level of water in the bucket the flow stops.

Explanation. In Fig. 2.36 it is easily seen that the 'head h of the water' (*i.e.* the depth of the open mouth of the tube below the level of water in the bucket) causes the flow of water. The greater this 'head' the greater is the pressure and so the faster the rate of flow. When there is no head of water, there is no flow of water.

The arrangement shown above is known as a **siphon.** It is a very simple device, which is easy to operate, and is used to transfer any liquid from a higher level to a lower level or to drain off the upper layer liquid in a vessel without disturbing the lower layer. Siphons are used to transfer liquids out of very heavy vessels or such containers which cannot be lifted easily. They are also used for transferring water from canals to low-level fields.

Siphon consists of a bent tube, with its two limbs of *unequal* length. It is first filled with the liquid, the ends being closed with the finger and placed in a position shown in Fig. 2.36. The finger is then removed and a steady stream of liquid flows through the tube from one vessel to other. The siphon will not work in the absence of the atmospheric pressure *i e*., in vacuum.

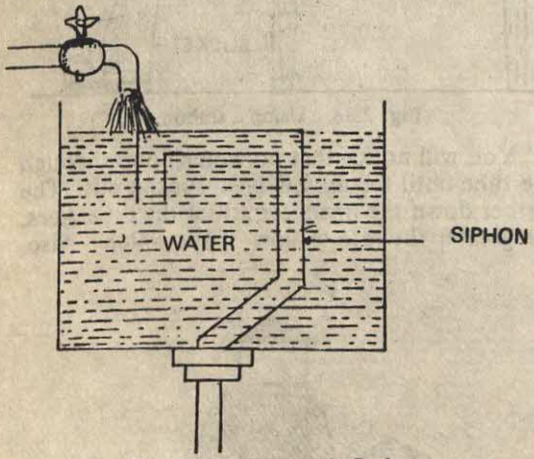


Fig. 2.37. Automatic flush

The principle of siphon is also utilised in the construction of automatic flushes, fitted in latrines, etc. A siphon is fitted inside a tank as shown in Fig. 2.37, with its longer limb passing out. A stream of water flows into the tank, and when the level of water reaches the bend, the siphon begins to work and the water flows out with great force till the level goes below the open end of the shorter limb.

2.9. BERNOULLI'S PRINCIPLE

We will consider in this section only the simplest kind of fluid flow—the flow along fixed paths known as **streamlines**, with turbulence and without viscosity (internal friction). By *streamline* flow we mean flow similar to that in Fig. 2.38. Any particle which finds itself at point A will be carried along a particular stream line and arrive at point B and later at point C. The flow is smooth and completely predictable. Similarly any particle A' will move from A' to B' to C'. This behaviour remains the same over time. There are no whirlpools or sudden changes of the kind as shown in Fig. 2.39 where much of the energy of the fluid is consumed in *turbulent motion* (or eddies) and eventually converted into heat. A streamline in general follows the shape of the tube through which the liquid (fluid) flows. Thus it may be straight or curved. A *tube of flow* consists of a number of streamlines forming a tube.

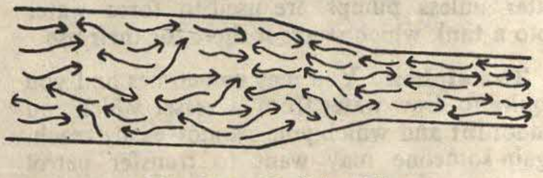


Fig. 2.39. Turbulent Flow

If we consider a small tube of liquid whose boundaries are set by streamlines as in Fig. 2.40 the velocity of the fluid may change as it flows along the tube. Suppose that at Q the velocity of the fluid is v_1 and the cross-sectional area A_1 and that at R the velocity is v_2 and the cross-sectional area A_2. Then for smooth,

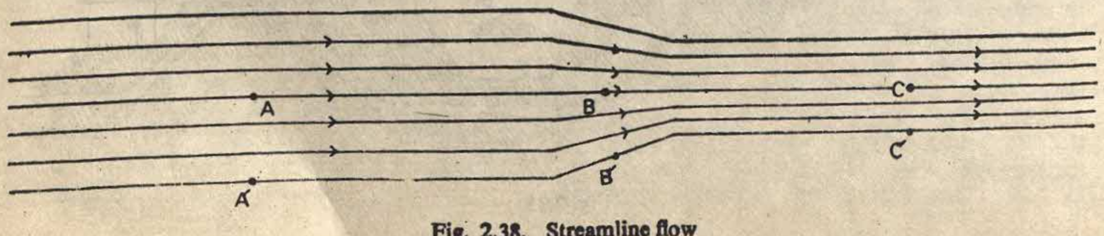


Fig. 2.38. Streamline flow

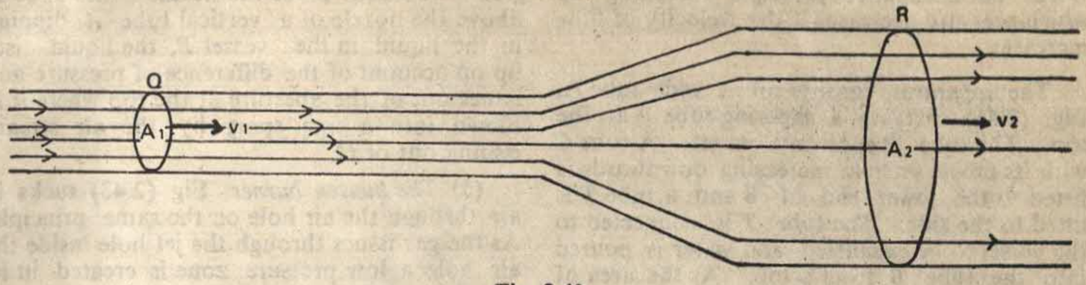


Fig. 2.40.

continuous flow (*i.e.* streamline flow), the mass of the fluid passing the point Q must be equal to the mass of the fluid passing the point R in the *same time interval t*. In time t, the mass passing Q is

$$\begin{aligned} m_1 &= \text{Volume} \times \text{density} \\ &= \text{length} \times \text{area} \times \text{density} \\ &= v_1 t \times A_1 \times \rho_1 \end{aligned}$$

where $v_1 t$ is the length of the fluid element passing Q in time t, and ρ_1 is the density of the fluid at Q.

Similarly, at R

$$m_2 = v_2 t \times A_2 \times \rho_2$$

Then, since the amount of fluid passing Q and R must be the same in equal times

$$\frac{m_1}{t} = \frac{m_2}{t}$$

or $$\frac{v_1 t A_1 \rho_1}{t} = \frac{v_2 t A_2 \rho_2}{t}$$

or $$v_1 A_1 \rho_1 = v_2 A_2 \rho_2$$

If we assume that the fluid is *incompressible*, so that its density does not change *i.e.* $\rho_1 = \rho_2$, then

$$\boxed{A_1 v_1 = A_2 v_2} \quad \text{or} \quad \boxed{\frac{A_1}{A_2} = \frac{v_2}{v_1}}$$

If $A_2 > A_1$, then $v_1 > v_2$.

This is the *equation of continuity*, which says that, *for streamline flow, the speed of flow of a fluid varies inversely with the cross-sectional area of the tube.* The velocity of the fluid is greater in the narrower parts of the pipe. For example, if there are constrictions in blood vessels in the human body, the blood must move more rapidly to get through these constrictions.

Daniel Bernoulli, the Swiss mathematician, observed a very interesting phenomenon. He found *that in a streamline fluid flow, the pressure is lower in the region where the flow is faster.* This is called **Bernoulli's Principle.** We may also state it in the following way.

"*When the speed of the fluid (liquid or gas) in a pipeline increases, the pressure decreases and conversely when the speed of the fluid decreases, the pressure increases.*

Applications of Bernoulli's Principle

(1) *Filter Pump or Aspirator.* It is a simple device for reducing the pressure in a vessel and

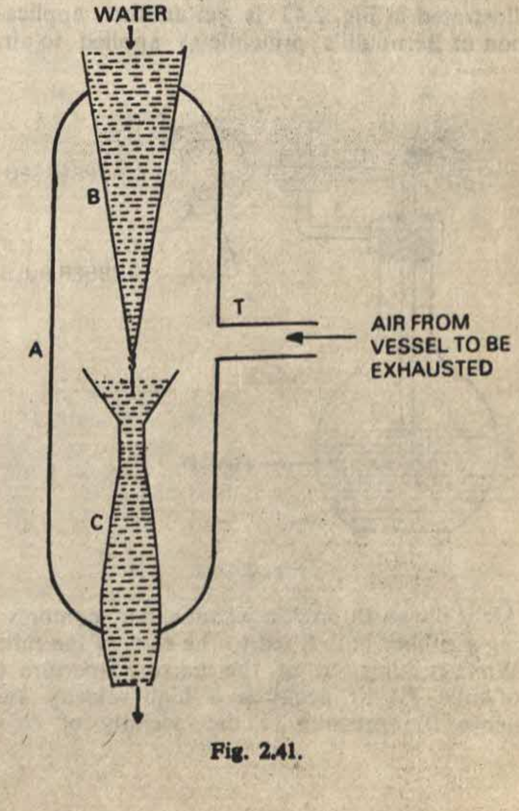


Fig. 2.41.

works on Bernoulli's principle according to which pressure decreases if the velocity of flow increases.

The apparatus consists of a wide tube A. Fig. (2.41), carrying a tapering tube B at the top. The tube *B* ends into a jet. A tube *C* with its cross section increasing downwards is fitted to the lower end of *B* and a tube *T* is fitted to the side. The tube *T* is connected to the vessel to be exhausted and water is poured into the tube *B* from a top. As the area of cross section of inner end of *B* is very small, water issues out of it with a very high velocity and hence at a very low pressure. On account of the low pressure at the nozzle of *B*, air rushes towards it from the vessel through the side tube *T* and is carried away by the stream of water down the discharge tube *C*. The pressure in the vessel can thus be made to fall to about 2 cm of mercury in a short time.

On account of the conical shape of tube *C* with diameter increasing downwards the velocity of flow of discharged water decreases and therefore the pressure increases and the tendency of the outer air to rush into the tube through *C* diminishes.

(2) *The Atomizer or Sprayer*. **Atomizer,** illustrated in Fig. 2.42 is yet another application of Bernoulli's principle as applied to air.

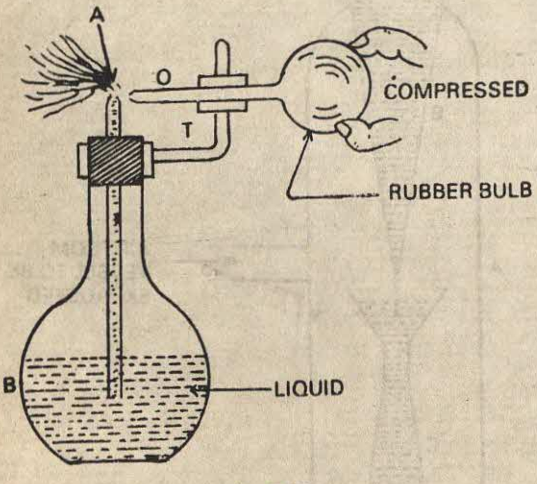


Fig. 2.42.

Air is blown through a jet tube *T* by compressing a rubber bulb fitted to the end of the tube. While rushing out of the narrow aperture *O* of tube *T*, air acquires a high velocity and hence the pressure in the vicinity of *O* is greatly reduced. Since the nozzle *O* lies directly above the nozzle of a vertical tube *A* dipping in the liquid in the vessel *B*, the liquid rises up on account of the difference of pressure and issues out of the aperture at the top where it is blown into a fine spray by the air stream issuing out of *O*.

(3) *The bunsen burner*, Fig (2.43) sucks in air through the air hole on the same principle. As the gas issues through the jet hole inside the air hole a low pressure zone is created in its vicinity and air is sucked inwards.

(4) *Lifting a Disc*. A tube *T* carries a disc *A* at its lower end Fig. 2.44 (*a*). *B* is a cardboard disc placed below it. On blowing air into the tube a low pressure area is created, by Bernoulli's principle, between the two discs when air flows out rapidly through the narrow space between the two discs and the external atmospheric pressure pushes the disc *B* up.

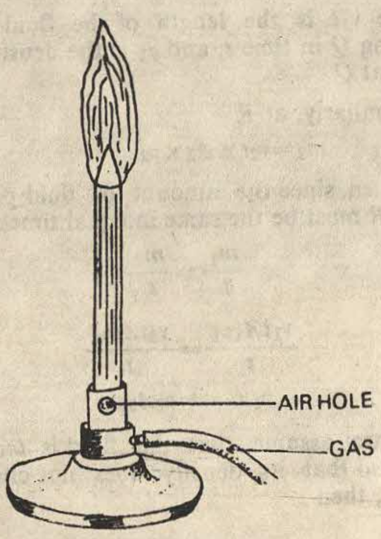


Fig. 2.43.

Similarly when two ping pong balls are suspended side by side and air is blown up through the space between the two, the air flows rapidly through the narrow space between the balls and the pressure falls. The atmospheric pressure from the sides brings the balls together.

The arrangement in Fig. 2.44 (*b*) illustrates a similar effect in the case of a ping pong ball in a funnel. When air is blown into the stem, the ball is sucked up by the difference of pressure.

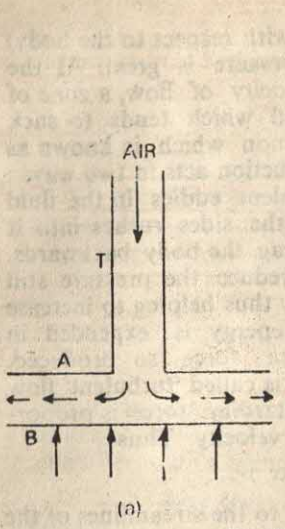


Fig. 2.44.

(5) *Magnus Effect*

When a sphere spins rapidly in air, the air surrounding it is also set into rotation in the same direction on account of friction of the sphere, forming concentric stream lines as shown in Fig. 2.45 (*a*). On the other hand if the sphere moves linearly the streamlines are as shown in Fig. 2.45 (*b*). If the sphere is moving linearly as well as rotating the streamlines at the top due to both types of motion are opposed to each other and those below are in the same direction. The velocity of air flow is therefore, greater below than above the sphere. Since an increase in velocity is accompanied by a lowering of pressure, the pressure on the lower side will be less than the pressure above and hence a resultant force acts upon the sphere at right angles to linear motion in the downward direction. This acts as a centripetal force and the sphere moves along a curved path Fig. 2.45 (*c*). This is called *Magnus Effect*. The rougher the surface of the sphere, the greater the effect. A cricket ball bowled with an initial spin in the hand, a tennis ball struck out of centre and a pistol bullet show this effect. It is to avoid Magnus effect that for distance shooting the bullets are given cylindrical shape and they are given an initial spin about their axis inside the barrel of the gun by guiding them along a screw thread inside the barrel. In this case, as the streamlines due to rotation are at right angles to the streamlines due to linear flight the velocity of air flow and hence pressure at the sides is uniform and therefore the flight is straight.

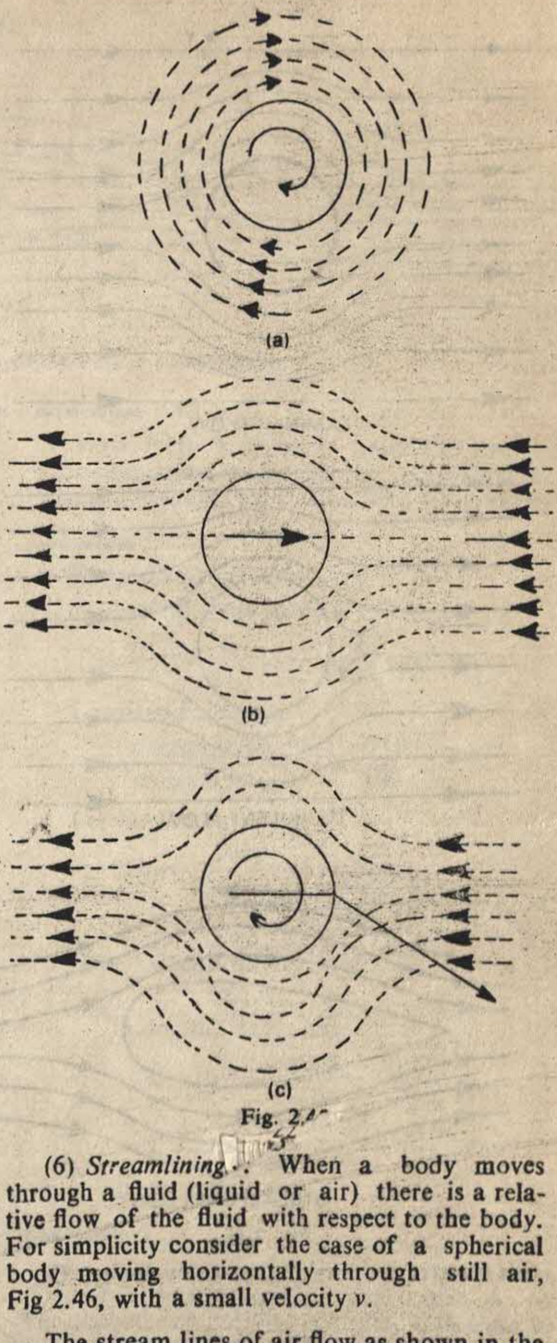
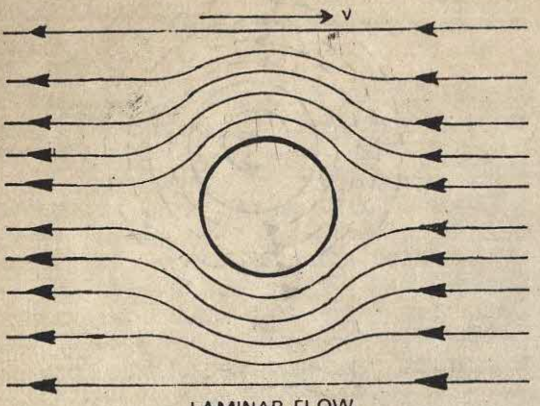


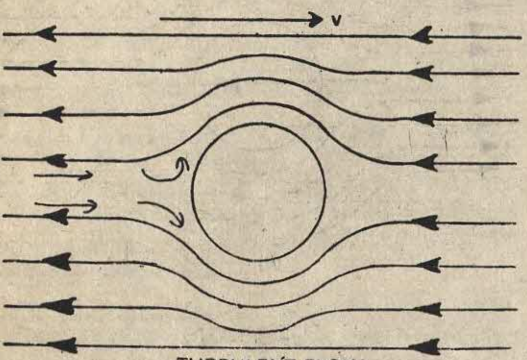
Fig. 2.45

(6) *Streamlining* : When a body moves through a fluid (liquid or air) there is a relative flow of the fluid with respect to the body. For simplicity consider the case of a spherical body moving horizontally through still air, Fig 2.46, with a small velocity *v*.

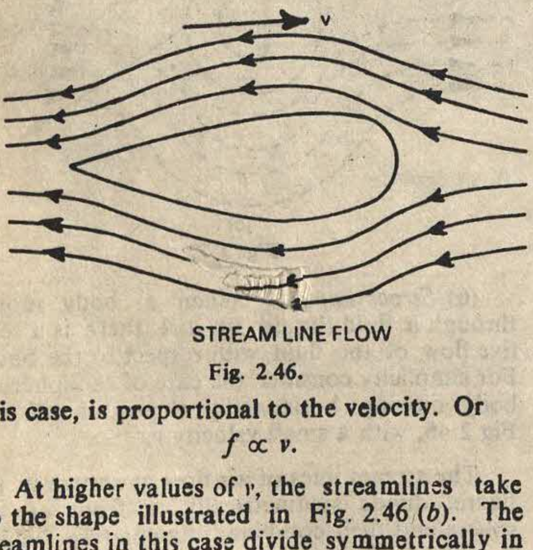
The stream lines of air flow as shown in the figure, divide symmetrically in front of the sphere and then combine immediately behind the sphere. Energy is expanded in overcoming friction of the air and in carrying some of mass of air in front of the sphere. Such a flow is called '*laminar*' *flow*. The retarding force in



LAMINAR FLOW



TURBULENT FLOW



STREAM LINE FLOW

Fig. 2.46.

this case, is proportional to the velocity. Or

$$f \propto v.$$

At higher values of v, the streamlines take up the shape illustrated in Fig. 2.46 (*b*). The streamlines in this case divide symmetrically in front of the body but they do not meet immediately behind the body but at a certain distance from it. On the front surface the fluid is stopped momentarily (with respect to the body) and therefore, the pressure is great. At the back, due to high velocity of flow, a zone of low pressure is created which tends to suck air into it—a phenomenon which is known as *tail suction*. This tail suction acts in two ways : (1) It gives rise to violent eddies in the fluid when the fluid from the sides rushes into it and (2) it tends to drag the body backwards. The eddies tend to reduce the pressure still further behind the body thus helping to increase the drag. Thus more energy is expended in overcoming the extra force so produced. This type of fluid flow is called 'turbulent' flow and in this case the retarding force is proportional to the square of velocity. Thus

$$f \propto v^2.$$

By shaping a body to the streamlines of the fluid through which it has to move, Fig. 2.46 (*c*), the retarding force may be considerably reduced. In that case the tendency to form *eddies* or *vortices* is greatly reduced and the body, as it were, slips through the fluid with a minimum disturbance, This is called *streamlining*. The *bodies* of *airplanes, torpedoes, ships, bombs* and *automobiles are stream-lined to avoid wastage of energy in movement through the fluid*, especially if they are to travel at high speeds. The man riding a race-bicycle bends his body forward in order to have a streamlined shape.

7. *Lift on an aircraft wing* :–

Fig. 2.47 shows the cross section of the wing of an aircraft. When the aircraft moves, the air flows both from under and above the wing. Aeroplane wings are so designed (*i.e.* streamlined) that the total distance travelled by air flowing over the wing is *longer* than that of the air flowing under it. Thus, the velocity of air flow above the wing must be higher than the velocity of air flow under the wing. From Bernoulli's Theorem we see that the pressure P_2 above the wing is lower than the corresponding pressure P_1 under the wing. The unbalanced pressure causes a force to act on it and pulls the aircraft up. This force can be resolved into two components—the vertical component produces the *lift* (*L*) and the horizontal component provides the *drift* (*D*) Low pressure region over the wing accounts for almost two-thirds of the upward force.

(8) *Carburettor* : The function of the carburettor is to deliver to the cylinder of a

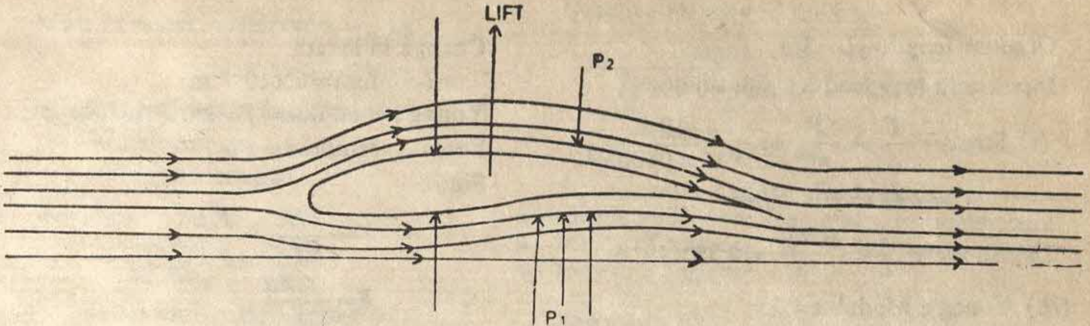


Fig. 2.47. Air flow across the wing of an aeroplane.

petrol engine a correctly proportioned mixture of petrol (in vapour form) and air. It is based upon Bernoulli's principle.

SOLVED EXAMPLES

Example 1 :

How much will a tungsten wire 1 m long and 1·00 mm in diameter stretch when a load of 1·0 kg is applied to it ?

Take $g=9{\cdot}8\ \text{m/s}^2$ and Young's modulus of tungsten wire$=4{\cdot}0\times10^{11}\ \text{N/m}^2$

Solution :

Given, original length$=L=1$ m

diameter of tungsten wire$=D=1{\cdot}00$ mm

$=1\times10^{-3}$ m

Load $(F)=Mg=1{\cdot}0\times9{\cdot}8$ N

Young's modulus$=Y=4{\cdot}0\times10^{11}\ \text{N/m}^2$

change in length$=l=$?

Since,

$$Y=\frac{\frac{F}{A}}{\frac{l}{L}}=\frac{\frac{F}{\left(\frac{\pi D^2}{4}\right)}}{\frac{l}{L}}\qquad\left(\because\ A=\frac{\pi D^2}{4}\right)$$

$$=\frac{4LF}{\pi D^2.\,l}$$

$\therefore$ change in length$=l$

$$=\frac{4LF}{\pi D^2 Y}=\frac{4LMg}{\pi D^2.\,Y}$$

$$=\frac{4\times1\times1{\cdot}0\times9{\cdot}8}{\frac{22}{7}\times(1{\cdot}0\times10^{-3})^2\times(4\times10^{11})}\ \text{m}$$

$$=\mathbf{3{\cdot}1\times10^{-5}\ m}$$

Example 2 :

How large a force is needed to stretch a 1 cm diameter steel road by 0.10 percent ? Young's modulus for steel$=20\times10^{11}$ dyne/cm².

Solution :

Here, diameter$=D=1$ cm

$\therefore$ Area of cross-section

$$=\frac{\pi D^2}{4}=\frac{22}{7}\times\frac{1}{4}=\frac{22}{28}\ \text{cm}^2$$

Longitudinal strain

$$=\frac{\text{change in length}}{\text{original length}}=\frac{0{\cdot}10}{100}$$

Let F=force needed

$$\therefore\ \text{Stress}=\frac{\text{Force}}{\text{area}}=\frac{F}{\left(\frac{\pi D^2}{4}\right)}$$

Now Young's modulus$=Y$

$$=\frac{\text{Stress}}{\text{Longitudinal strain}}$$

$$\text{or}\qquad 20\times10^{11}=\frac{F\times4}{\pi D^2}\times\frac{100}{0{\cdot}10}$$

$$\therefore\ F=20\times10^{11}\times\frac{22}{7}\times\frac{1}{4}\times\frac{0{\cdot}10}{100}\ \text{dyne}$$

$$=1{\cdot}57\times10^{9}\ \text{dyne}$$

Example 3 :

An extension of 1 mm is observed in a wire of length 3 metre, when it is loaded with 19·6N. The diameter of the wire is 1 mm. Calculate (*i*) the stress (*ii*) the strain (*iii*) Young's Modulus of elasticity of the wire. Take $g=9{\cdot}8\ \text{ms}^{-2}$

Solution ;—Given, $F=19{\cdot}6$ N

radius$=r=\frac{1}{2}$ mm$=0{\cdot}0005$ m

$g=9{\cdot}8\ \text{ms}^{-2}$

Original length $= L = 3\text{m}$

Increase in length $= l = 1\ \text{mm} = 0{\cdot}001\ \text{m}$

$$(i)\ \text{Stress} = \frac{F}{A} = \frac{F}{\pi r^2} = \frac{19{\cdot}6}{3{\cdot}14 \times ({\cdot}0005)^2}$$

$$= 2{\cdot}495 \times 10^7\ \text{N}/m^2$$

$$(ii)\ \text{Strain} = \frac{l}{L} = \frac{0{\cdot}001}{3} = \mathbf{0{\cdot}33 \times 10^{-3}}$$

(*iii*) Young's Modulus $= Y$

$$= \frac{\text{Stress}}{\text{Strain}} = \frac{2{\cdot}495 \times 10^7}{0{\cdot}33 \times 10^{-3}}$$

$$= \mathbf{7{\cdot}484 \times 10^{10}}\ \text{N/m}^2$$

Example 4 :

What mass must be suspended from a steel wire 4 m long and 1 mm in diameter to stretch it by 2 mm. Young's Modulus for steel is $2 \times 10^{11}\ \text{N}\ m^{-2}$.

Solution :

Given, original length $L = 4$ m

Radius $= r = 0{\cdot}5\ \text{mm} = 0{\cdot}005$ m

Increase in length $= l = 2\ \text{mm} = 0{\cdot}002$ m

$Y = 2 \times 10^{11}\ \text{N/m}^2$

$g = 9{\cdot}8\ \text{m/s}^2$

Mass $= M = ?$

Since, Young's Modulus

$$(Y) = \frac{\text{Stress}}{\text{Strain}} = \frac{Mg}{\pi r^2} \times \frac{L}{l}$$

$$\therefore \quad \text{Mass} = M = Y \frac{\pi r^2 \,.\, l}{L \,.\, g}$$

$$= \frac{2 \times 10^{11} \times 3{\cdot}14 \times (0{\cdot}0005)^2 \times 0{\cdot}002}{9{\cdot}8 \times 4}$$

$= \mathbf{8{\cdot}012\ kg}$

Example 5.

A steel rail is 13 m in length and has an area of cross-section of 40 cm². Between night and day, the change in length is 6mm. What force parallel to the rail would be required to prevent this increase in length ? Young's modulus for steel is $2{\cdot}0 \times 10''\ \text{N/m}^2$.

Solution

Here,

Original length $= L = 13$ m

Area of cross-section

$= A = 40\ \text{cm}^2 = 4 \times 10^{-3}\ \text{m}^2$

Change in length

$= l = 6\ \text{mm} = 6 \times 10^{-3}$ m

Young's modulus $= Y = 2{\cdot}0 \times 10^{11}\ \text{N/m}^2$

Force required $= F = ?$

Since,

$$Y = \frac{F/A}{l/L} = \frac{F.L}{A.l}$$

$$\therefore \quad F = \frac{Y.A.l}{L}$$

$$= \frac{2{\cdot}0 \times 10^{11} \times 4 \times 10^{-3} \times 6 \times 10^{-3}}{13}\ \text{N}$$

$$= \mathbf{3{\cdot}69 \times 10^5\ N}$$

Example 6.

An iron cube of volume 800 cm³ is totally immersed in (*i*) Water (*ii*) Oil of density 0·8 g/cm³ (*ii*) Oxygen gas of density 0·0015 g/cm³. Calculate the upward thrust in each case. (Take $g = 1000\ \text{cms}^{-2}$) Density of water $= 1\ \text{g/cm}^3$.

Solution.

Upward thrust = Weight of fluid displaced

(*i*) ∵ Upthrust = Weight of 800 cm³ of water

$= \text{mass} \times \text{Acc. due to gravity}$

$= \text{volume} \times \text{density} \times g$

$= 800 \times 1 \times 1000$ dyne

$$= \frac{800 \times 1000}{10^5} = 8\ \text{N}$$

(*ii*) ∴ Upthrust

= Weight of 800 cm³ of oil

$= 800 \times 0{\cdot}8 \times 1000$ dyne

$$= \frac{800 \times 0{\cdot}8 \times 1000}{10^5} = 6{\cdot}4\ \text{N}$$

(*iii*) ∴ Upthrust

= Weight of 800 cm³ of oxygen

$= 800 \times 0{\cdot}0015 \times 1000$ dynes

$$= \frac{800 \times 0{\cdot}0015 \times 1000}{10^5} = 0{\cdot}012\ \text{N}$$

Example 7.

A metal cube weighs 10N in air (mass 1 kg) and 8N when totally immersed in water. Calculate its volume and density.

(Take $g = 10\ \text{ms}^{-2}$).

Solution.

We have, Upthrust = 10 N—8 N = 2 N

or 2N = weight of water displaced

$\therefore$ Mass of water displaced $=\frac{2}{10}$ kg

$=200$ g

$\therefore$ Volume of water displaced

$=200\ cm^3$

$=$ Volume of cube

$\therefore$ Density

$$=\frac{\text{Mass}}{\text{Volume}}=\frac{1000}{200}$$

$$=5\ g/cm^3=5000\ kg/m^3$$

Example 8.

An iron cube, mass 480 g and density 8 g/cm^3, is suspended half-immersed in an oil of density of 0·9 g/cm^3. Find the tension in the suspension. (Take acceleration due to gravity$=10\ ms^{-2}$)

Solution.

Weight of iron cube

$$=\frac{480}{1000}\times 10=4{\cdot}8\ N$$

Volume of cube

$$=\frac{\text{Mass}}{\text{Density}}=\frac{480}{8}=60\ cm^3$$

$\therefore$ Upthrust

$=$Weight of 30 cm^3 of oil

$=30\times 0{\cdot}9\times 1000$ dyne

$$=\frac{30\times 0{\cdot}9\times 1000}{10^5}=0{\cdot}27\ N$$

$\therefore$ Tension in String (apparent weight)

$=4{\cdot}8-0{\cdot}27=$ **4·53 N**

Example 9.

A body weighs 60 g in air and 42 g in water. Find its volume and density.

Solution :

Weight of the body in air$=60$ g

Weight of the body in water$=42$ g

$\therefore$ Loss of weight of body in water

$=60-42$

$=18$ g

$\therefore$ Loss of weight in water

$=$Weight of an equal volume of water displaced by the body.

$\therefore$ Volume of the body is numerically equal to the loss of weight in water *i.e.*, 18 cm^3.

Relative Density of the body

$$=\frac{\text{Weight of the body in air}}{\text{Loss of weight of body in water}}$$

$$=\frac{60}{18}=3{\cdot}3$$

Since relative density of a body is the density of the body over the density of water and as density of water is 1 g/cm^3, therefore, density of body is **3·3 g/cm^3.**

Example 10.

A piece of glass weighs 8·6 g in air, 5·17 g in water and 6·4 in alcohol Find the relative density of alcohol.

Solution.

Weight of the glass piece in air$=8{\cdot}60$ g

Weight of the glass piece in water$=5{\cdot}17$ g

Weight of the glass piece in alcohol$=6{\cdot}40$ g

$\therefore$ Loss of weight of glass piece in water

$=8{\cdot}60-5{\cdot}17$

$=3{\cdot}43$ g

and Loss of weight of glass piece in alcohol

$=8{\cdot}60-6{\cdot}40$

$=2{\cdot}20$ g

$\therefore$ Relative density of alcohol

$$=\frac{\text{Loss of weight of glass piece in alcohol}}{\text{Loss of weight of glass piece in water}}$$

$$=\frac{2{\cdot}20}{3{\cdot}43}=\mathbf{0{\cdot}64}$$

Example 11.

A cylindrical cup with 14 cm as external diameter and 5 cm as height weighing 462 g is placed on the surface of water. How much of it will go into the water and how much, if any, will remain out of it ?

Solution.

Diameter of the cup$=14$ cm$=2r$

$\therefore$ radius$=r=7$ cm

Height of the cup$=5$ cm

Weight of the cup$=462$ g

Suppose x cm of cup goes into water.

Now from the conditions of equilibrium of a floating body, we know that

Weight of the liquid displaced

$=$Weight of the body

∴ Volume of water displaced × density of water $=462$

or $(\pi r^2)x\times\rho=462$

where ρ = density of water

or $\frac{22}{7}\times7\times7\times x\times1=462$

$$x=\frac{462\times7}{22\times7\times7}=\mathbf{3\ cm}$$

∴ Height of the cup which remains out of water $=5-3=$ **2 cm**

Example 12.

A beaker of water is placed on a balance pan and counterpoised. A piece of iron weighing 15 g suspended by a thread is lowered into the beaker until it is completely submerged without touching the beaker. What weight must be added to restore equilibrium and in what direction ? (density of iron $=7{\cdot}5$ g/cm^3)

Solution.

Mass of iron piece $=15$ gm

Density of iron piece $(\rho)=7{\cdot}5$ gm/cm^3

$$\because\quad \rho=\frac{\text{Mass}}{\text{Volume}}$$

$$\therefore\quad 7{\cdot}5=\frac{15}{V}$$

or $V=2$ cm^3

∴ Upward thrust of water on the iron piece

= Wt. of water displaced by the iron piece

= Wt. of an equal volume of water

= Wt. of 2 cm^3 of water

= 1960 dyne

= Weight of 2 g of water

This upward thrust is experienced by the hand which holds the iron piece.

By the third law of motion, water experiences an equal **downward** thrust. This downward thrust acts on the bottom of the beaker. In order to balance it, a weight of 2 gm must be added to the second pan of the balance.

Example 13.

What volume of cork of density $0{\cdot}25$ g/cm^3 must be tied to a lump of platinum of density $21{\cdot}5$ g/cm^3 weighing 95 gm in order that the density of the resulting object may be 10 g/cm^3.

Solution.

Density of the cork $=\rho_1=0{\cdot}25$ g/cm^3

Density of platinum $=\rho_2=21{\cdot}5$ g/cm^3

Let mass of the cork $=m_1$ g

Mass of platinum $=m_2=95$ g

Average density (ρ) of the resulting object $=10$ g/cm^3

Since, density of the resulting object

$$=\frac{\text{Total Mass}}{\text{Total Volume}}$$

$$\therefore\quad \rho=\frac{m_1+m_2}{\dfrac{m_1}{\rho_1}+\dfrac{m_2}{\rho_2}}$$

$$\text{or}\quad 10=\frac{m_1+95}{\dfrac{m_1}{0{\cdot}25}+\dfrac{95}{21{\cdot}5}}$$

$$\therefore\quad m_1=\frac{2185}{43\times39}\text{ g}$$

∴ Volume of the cork

$$=\frac{m_1}{\rho_1}=\frac{2185}{43\times39\times0{\cdot}25}$$

$$=\mathbf{5{\cdot}212\ cm^3}$$

Example 14.

A glass tube 30 cm long and $\frac{1}{2}$ cm^2 in cross section is closed at one end ; its weight is 4 g and 10 g of mercury are poured into it. What will be the density of a liquid in which it floats vertically with 2 cm length of its stem above the surface ?

Solution.

Length of the tube $=30$ cm

Area of cross-section of the tube $=\frac{1}{2}$ cm^2

Weight of the tube $=4$ g

Weight of mercury $=10$ g

∴ Weight of tube containing mercury $=4+10=14$ g

Length of the tube outside the liquid $=2$ cm

∴ Length of the tube inside the liquid $=30-2=28$ cm

∴ Volume of liquid displaced

$$=28\times\frac{1}{2}=14\text{ cm}^3$$

Now, for equilibrium

Weight of the liquid displaced

$= $ Weight of the floating body

or $14 \times \rho = 14$

or $\rho = \mathbf{1\ g/cm^3 = 1000\ kgm^{-3}}$

Example 15.

A solid body floating in water has $\frac{1}{6}$th of its volume above the surface. What fraction of its volume will project if it floats in a liquid of density 1·2 g/cm³ ?

Solution.

Let the volume of the solid body $= V$ cm³

Volume of the solid body above water surface $= \frac{V}{6}$ cm³

$\therefore$ Volume of the solid body inside water surface

$$= V - \frac{V}{6} = \frac{5}{6} V \text{ cm}^3$$

Weight of the solid body

$=$ Upward thrust of water on the solid body

$=$ Wt. of water displaced by the immersed part of the body

$$= \frac{5}{6} V \times 1 \times g$$

$$= \frac{5}{6} V\,g \qquad \ldots(1)$$

Let the volume of the solid body projecting outside the liquid of density 1·2 g/cm³ be x.

$\therefore$ Volume of the solid body inside the liquid $= (V - x)$ cm³

Again, wt. of the solid body

$=$ Upward thrust of liquid on the solid body

$=$ Wt. of the liquid displaced by its immersed part

$$= (V - x) \times 1{\cdot}2\ g \qquad \ldots(2)$$

Since (1) and (2) are equal,

$$\therefore \quad (V - x)\, 1{\cdot}2 = \frac{5}{6} V$$

$$\therefore \qquad x = \frac{2{\cdot}2}{7{\cdot}2} V = \frac{\mathbf{11}}{\mathbf{36}} \mathbf{V}$$

Example 16.

A silver ornament is suspected to be hollow. Its weight is 288·75 g and it can displace 30 cm³ of water. If the density of silver is 10·5 g/cm³, find the volume of the cavity.

Solution.

Mass of the silver ornament $= 288{\cdot}75$ g

Density of silver $= \rho = 10{\cdot}5$ g/cm³

$\therefore$ Real volume of silver

$$= \frac{\text{mass}}{\text{density}}$$

$$= \frac{288{\cdot}75}{10{\cdot}5}$$

$$= 27{\cdot}5 \text{ cm}^3$$

But the apparent volume of the ornament

$=$ Volume of water which it can displace

$= 30$ cm³

$\therefore$ Volume of cavity inside the ornament

$= 30 - 27{\cdot}5$

$= \mathbf{2{\cdot}5\ cm^3}$

Example 17.

Osmium is the densest of the elements. Its density is $22{\cdot}5 \times 10^3$ kg/m³. What will be the weight of a cube of osmium of side 5 cm, when weighed in air, in water and in mercury ? (Take $g = 9{\cdot}8\ \text{ms}^{-2}$). Density of water

$= 1000$ kg/m³ and density of mercury

$= 13{\cdot}6 \times 10^3$ kg/m³.

Solution.

Given, side of the cube of osmium

$= 5 \text{ cm} = 5 \times 10^{-2}$ m

Volume of the cube of osmium

$= 5 \times 10^{-2} \times 5 \times 10^{-2} \times 5 \times 10^{-2}$ m³

$= 12{\cdot}5 \times 10^{-5}$ m³

density of osmium $= 22{\cdot}5 \times 10^3$ kg/m³

$\therefore$ Weight of cube of osmium in air

$=$ Volume $\times$ density $\times$ Acceleration due to gravity

$= 12{\cdot}5 \times 10^{-5} \times 22{\cdot}5 \times 10^3 \times 9{\cdot}8$ N

$= \mathbf{27{\cdot}56\ N}$.

Weight in water

Upward thrust experienced by the cube of osmium in water

$=$ weight of water displaced by the cube of osmium

$=$ Volume of water displaced $\times$ density of water $\times$ Acc due to gravity

$= (12{\cdot}5 \times 10^{-5}) \times (1000) \times 9{\cdot}8$ N

$= 1{\cdot}225$ N

$\simeq 1{\cdot}23$ N

∴ Weight of the cube of osmium in water
=Weight of cube of osmium in air −upward thrust experienced by the cube of osmium in water

$=27{\cdot}56\text{ N}-1{\cdot}23\text{ N}$

$=26{\cdot}33$ **N.**

Weight in mercury

Upward thrust experienced by the cube of osmium in mercury
=Weight of mercury displaced by the cube of osmium

$=(12{\cdot}5\times10^{-5})\times(13{\cdot}6\times10^{3})\times9{\cdot}8\text{ N}$

$=16{\cdot}66$ N.

Weight of the cube of osmium in mercury
=Weight of the cube of osmium in air − upward thrust experienced by the cube of osmium in mercury

$=27{\cdot}56-16{\cdot}66$

$=\mathbf{10{\cdot}90}$ **N.**

Example 18.

A girl weighing 50 kg walks on high heels. Suppose the area of the heel is 1 cm², what is the pressure in S.I. units on the ground when only one heel is in contact with it ?

(Tage $g=9{\cdot}8\text{ ms}^{-2}$)

Solution.

Here, force$=mg=$weight of the girl

$=50\times9{\cdot}8\text{ N}$

$=490\text{ N}$

area of the heel$=1\text{ cm}^2$

$=1{\cdot}0\times10^{-4}\text{ m}^2$

$$\therefore\ \text{Pressure}=\frac{\text{force}}{\text{area}}$$

$$=\frac{490}{1{\cdot}0\times10^{-4}}\text{ N/m}^2$$

$$=\mathbf{4{\cdot}9\times10^{6}\ N/m^2.}$$

Example 19.

Pressure of air at ground level is the same as that of a column of 0·76 m of Hg. How much is it in N/m² ? What will be the height of a water column that has the same pressure ?

(Take $g=9{\cdot}8\text{ m/s}^2$). Density of mercury $=13{\cdot}6\times10^{3}\text{ kg/m}^3$ and density of water $=1000\text{ kg/m}^3$.

Solution.

Pressure of air at ground level

$=P=h\rho g$

$=0{\cdot}76\times13{\cdot}6\times10^{3}\times9{\cdot}8\text{ N/m}^2$ (or Pa)

$=1{\cdot}01\times10^{5}\text{ N/m}^2$

Now, for water

$\rho=10^{3}\text{ kg/m}^3$,

and so $h=\dfrac{P}{\rho g}=\dfrac{1{\cdot}01\times10^{5}}{10^{3}\times9{\cdot}8}=\mathbf{10{\cdot}33\ m}$

Hence the height of water column must be 10·33 m.

Example 20.

Water flows through a pipe of 2 cm internal diameter at the rate of 8 litres/min. What is the speed of water ?

Solution.

Given, rate of flow of water through a pipe

$=8$ litres/min

$$=\frac{8\times10^{-3}}{60}\text{ m}^3\text{/s}$$

Internal diameter of the pipe$=2\times10^{-2}$ m

∴ Internal radius of the pipe

$=r=1\times10^{-2}$ m

Area of cross-section of the pipe

$=A=\pi r^2$

$$=\frac{22}{7}(1\times10^{-2})^2\text{ m}^2$$

Let speed of water $=v$

Since, rate of flow of water through the pipe $=Av$

$$\therefore\quad \frac{8\times10^{-3}}{60}=\frac{22}{7}(1\times10^{-2})^2\times v$$

or $\qquad v=\mathbf{0{\cdot}42\ m/s}$

Example 21.

Cold water circulates through a house from the main water pipe in the basement. The water enters the house through an 8·0 cm diameter pipe at a flow speed of 0·60 m/s under a pressure of $4{\cdot}0\times10^{5}\text{ N/m}^2$. What is the flow speed of the water in a 5·0 cm diameter pipe on the third floor, which is 9·0 m above the main water pipe in the basement ?

Solution.

From the equation of continuity for fluid flow, we know that the flow speed and the cross-sectional area of the pipe at any two points along the pipe are related by the equation

$$A_1v_1=A_2v_2$$

Hence, $v_2=\dfrac{A_1}{A_2}\cdot v_1$

Here, $A_1=\pi\,(0{\cdot}040\text{ m})^2$; $A_2=\pi\,(0{\cdot}025\text{ m})^2$; $v_1=0{\cdot}60$ m/s.

$$\therefore \quad v_2=\frac{\pi\,(0{\cdot}040\text{ m})^2}{\pi\,(0{\cdot}025\text{ m})^2}\cdot(0{\cdot}60\text{ m/s})$$

$$=\mathbf{1{\cdot}5\ m/s}$$

SUMMARY

1. Solids are generally identified by the fact that they retain their shape indefinitely and resist forces that tend to change their shape.
2. *Stress* is a restoring force per unit area and is measured in unit of force per unit area. Its S.I. unit is N/m².
3. *Strain* is the change in size or shape of a solid produced by an applied stress. Being a ratio of the same physical quantities, it has no unit.
4. *Young's modulus* is the ratio of stress to longitudinal strain.

$$Y=\frac{(F/A)}{(l/L)}$$

$$=\frac{(F/\pi r^2)}{(l/L)}\text{ for a wire of radius } r.$$

Its unit is N/m².

5. According to *Hooke's law*, the strain produced in a solid is directly proportional to the applied stress, so long as the stress does not exceed the elastic limit.
6. *Elastic limit* is that value of the stress beyond which Hooke's law is no longer valid.
7. One of the basic properties of a liquid is that it takes the shape of the vessel which holds it.
8. Free surface of a liquid at rest is always horizontal.
9. The surface of a liquid behaves as if it were a stretched, thin, elastic skin, which always tends to be as small as possible. The force which causes the surface of a liquid to behave like a stretched elastic skin is called *surface tension*.

   The magnitude of the force depends upon (*i*) the nature of the liquid, and (*ii*) the medium in contact with it.
10. Contaminating a liquid surface reduces its surface tension.

    Surface tension diminishes with rise in temperature.
11. The property possessed by a liquid to rise or fall in a narrow tube is called *capillarity*. The rise or fall in level depends directly upon the surface tension of the liquid and inversely on the diameter of the capillary tube.
12. According to *Archimede's principle*, an object partially or totally submerged in a fluid (liquid or gas) is buoyed up by a force equal to the weight of the fluid which the object displaces.
13. Density of a solid $(\rho)=\dfrac{\text{Weight of the object in air}}{\text{Loss of weight of the object in water}}\times$ Density of water
14. Pressure $=\dfrac{\text{Force}}{\text{Area}}$

    Its S.I. unit is N/m². This unit is also known as *pascal* (symbol Pa).

    If the force on every unit area of a surface is the same, the pressure is called *uniform pressure*.
15. The pressure at a point inside a homogeneous liquid is the same in all directions.
16. The pressure of a homogeneous liquid at all points in the same horizontal plane is the same.
17. According to *Pascal's law* whenever pressure is applied on any part of a liquid contained in a vessel, it is transmitted undiminished and equally in all directions.
18. Pressure (*P*) at any point at a depth '*h*' in a fluid (liquid or gas) of density ρ is $h\rho g$ where g is the acceleration due to gravity at a place *i.e.*, $\boxed{P=h\rho g}$. Thus pressure in a fluid increases with depth. The denser a fluid, the greater the pressure it exerts.

19. On earth, the pressure due to the weight of the air in the earth's atmosphere is called *atmospheric pressure.*

1 atmosphere (symbol atm) $= 1{\cdot}01 \times 10^5$ N/m^2 (or *Pa*).

20. *Rate of flow* of a fluid is the volume of the fluid that flows out of a pipe in one second.

21. *Equation of continuity* : $\boxed{A_1v_1 = A_2v_2}$.

This equation says that for a stream-line flow, the speed of flow of a fluid varies inversely with the cross-sectional area of the tube.

22. According to *Bernoulli's principle*, in a stream-line fluid flow, when a speed of the fluid (liquid or gas) in a pipeline increases, the pressure decreases, and conversely when the speed of the fluid decreases, the pressure increases.

23. Water seeks its own level. That is why all surfaces of liquids are horizontal. Town water supply is an example of a liquid finding its own level.

QUESTIONS

[A] Objective-type Questions :

1. Solids and liquids have a......shape.

2. ......is the S.I. unit of stress.

3. The S.I. unit of atmospheric pressure is
   - (*i*) joule
   - (*ii*) pascal
   - (*iii*) newton
   - (*iv*) newton/metre

4. A plastic body acquires a.........deformation.

5. Buoyancy is
   - (*a*) a downward force
   - (*b*) pressure
   - (*c*) momentum
   - (*d*) an upward thrust

6. When a body is partly immersed in a liquid, it experiences an upward thrust equal to
   - (*a*) the weight of the liquid displaced by its immersed part.
   - (*b*) the weight of the liquid displaced by its part which is not immersed.
   - (*c*) the weight of the whole body.

7. If the weight of a solid body is equal to the upward thrust experienced by it whenever it is immersed in a liquid, the body will
   - (*a*) sink
   - (*b*) float
   - (*c*) rise

8. In question 7, the resultant force is
   - (*a*) zero
   - (*b*) greater than zero
   - (*c*) less than zero

9. In SI system, the unit of density is.........

10. Density of a solid $= \dfrac{\text{Weight of solid in air}}{\text{.........................}} \times$ density of water

11. Pressure is defined as...........per unit..............

12. In SI system, pressure is expressed as ....

13. Pressure at any point at a depth 'h' in a liquid of density ρ is
    (*a*) $h \rho g$
    (*b*) $\dfrac{hg}{\rho}$
    (*c*) $\dfrac{h\rho}{g}$
    (*d*) $2 h \rho g$
    (*e*) zero

14. Whenever a pressure is applied on any part of a liquid contained in a vessel it is transmitted
    (*i*) undiminished and equally in all directions
    (*ii*) undiminished and unequally in all directions
    (*iii*) diminished and equally in all directions
    (*iv*) undiminished and equally in some directions.

15. Hydraulic lift is based on
    (*a*) Newton's first law of motion
    (*b*) Pascal's law
    (*c*) Archimede's Principle
    (*d*) Bernoulli's Principle

16. The earth's surface is surrounded by a thick layer of..............called the.........and the force due to the weight of this column of...........per unit area is called the..........

17. 1 millibar$=$...........Nm^{-2}
    1 atm$=$...........$Nm^{-2}=$.............. dyne/cm$^2=$...........bar

18. Stress per unit longitudinal strain is equivalent to
    (*a*) pressure
    (*b*) density
    (*c*) Young's modulus
    (*d*) velocity
    (*e*) acceleration

19. A block of wood (density 800 kg m^{-3}) is placed gently into a beaker of ethanol (density 800 kg m^{-3}). The block of wood will
    (*a*) float with half its volume in the ethanol, half its volume in the air
    (*b*) sink to the bottom of the beaker
    (*c*) float just completely submerged
    (*d*) sink to the centre of the ethanol with all of the block submerged
    (*e*) float on the surface of the ethanol with most of the block in the air

20. *Aerofoil lift* is due to
    (*a*) faster airflow over the top surface than over the bottom surface
    (*b*) slower airflow over the top surface than over the bottom surface
    (*c*) equal airflow over the top surface and the bottom surface

21. Surface tension tries to minimise the..............of a given mass of liquid.

22. The rise in level of a liquid in a capillary tube depends directly upon the........ ...of the liquid and............on the diameter of the tube.

23. A siphon is used to transfer any liquid from
    (*i*) a lower level to a higher level
    (*ii*) a higher level to a lower level
    (*iii*) one point to another point at the same level.

24. A pressure of 10^6 dyne/cm^2 is equal to a pressure of
    (*i*) 10^7 N/m^2
    (*ii*) 10^5 N/m^2
    (*iii*) 10^4 N/m^2

25. Pressure difference between two levels depends
    (*i*) on the way the two levels are connected
    (*ii*) on the level difference
    (*iii*) none of the above

[B] Very Short Answer-Type Questions :

1. Mention SI unit of stress.
2. Mention S.I. unit of strain.
3. Give S.I. unit of Young's modulus.
4. What is buoyancy ?
5. Give the mathematical statement of Hooke's Law.
6. What is the effect of contamination on surface tension of water ?
7. If we raise the temperature of water, will its surface tension increase or decrease ?
8. Give an example of capillary action.
9. Define pressure
10. Mention S.I. unit of pressure.
11. If you fill the tin with water, water will sprout out of the holes which are at the same height on the tin. Will water fall at the same distance from the periphery of the tin ?
12. A body whose volume is 0·05 m^3 is immersed in water. What is the volume of water displaced by it ?
13. Give one example of a perfect fluid.
14. How are pressure and force related to each other ?
15. What formula is used to calculate pressure at any point at a depth 'h' in a liquid of density ρ where acceleration due to gravity is 'g' ?
16. Define rate of flow of a fluid.
17. What is equation of continuity ?

18. A liquid flows continuously through a pipeline of non-uniform cross-section. What happens to the velocity of the liquid in the narrower parts of the pipe ?

19. The wings of the aeroplane are so designed that the air blowing above the wings is speeded up. What happens to the pressure of air on the top of the wing ?

20. What is an elastic limit ?

21. Name two practical applications of Pascal's law.

22. Mention two practical applications of Bernoulli's principle.

23. Mention a common property of all fluids.

24. Is pressure a vector quantity ?

25. Name that property of water due to which it wets the cloth even when a small part of it is dipped in it.

26. Name two physical quantities having the same unit : Nm^{-2} ? *[A.I.S.S. 1987]*

27. Give reason why atoms in a substance attain equilibrium at some well defined separation. *[A.I.S.S. 1987]*

[**Hint** : At this separation force of attraction balances the force of repulsion.]

[C] **Short Answer Type and Essay Type Questions** :

1. Explain the following terms :
   (*i*) Elasticity (*ii*) Stress (*iii*) Strain
   (*iv*) Hooke's law (*v*) Modulus of Elasticity (*vi*) Longitudinal strain
   (*vii*) Elastic limit (*viii*) Young's Modulus

2. Which is more elastic, iron or rubber ? Why ?

3. (*a*) Define longitudinal strain and Young's modulus of a given wire. Mention their units in S.I. system.

   (*b*) How will you determine Young's modulus of a given wire experimentally ?

4. (*a*) Draw and explain stress-strain graph in case of a wire which is gradually loaded.

   (*b*) From the above graph explain the properties, (*i*) elasticity (*ii*) plasticity (*iii*) brittleness (*iv*) ductility and (*v*) malleability, of the materials.

5. In Fig. (2.2) when we place weights in the hanger, a force *mg* (*m* includes the mass of the hanger) is applied to the wire and acts vertically down. Since the wire does not move, an equal and opposite force must be acting on it. Which is this force and how does it arise ?

6. What is buoyancy ? Name two factors that influence buoyant force.

7. State the principle of Archimedes. How it can be verified experimentally.

3. Show that when a body floats in a liquid, the weight of the body in air is equal to the weight of the liquid displaced by it.

9. Explain how one can determine the relative density of a liquid by weighing a solid body suspended inside it.

10. If we have a solid body whose density is exactly equal to that of water, what will happen to it if we drop it in water ? Will it sink or float ?

11. Explain why :
   (*i*) An iron piece sinks in water while a ship floats.

(*ii*) It is easier to swim in sea-water than in river-water.

(*iii*) Ice floats on the surface of water.

(*iv*) A balloon filled with hydrogen gas rises in air.

12. (*a*) Distinguish between density and relative density of a substance. Give SI units in which they are measured.

(*b*) How will you determine the density of a solid heavier than but insoluble in water by Archimedes' principle ?

13. Explain what is meant by (*a*) the pressure on the surface (*b*) the pressure at a point in a liquid.

14. Describe an experiment to show that equal pressure is exerted in all directions at a point in a liquid at rest.

15. State Pascal's law and describe an experiment to demonstrate it.

16. (*a*) Distinguish between force (thrust) and pressure and mention the SI units in which both these quantities are measured ?

(*b*) Deduce an expression for the pressure at any point in a liquid at rest.

17. (*a*) What is an atmosphere ?

(*b*) Describe two simple experiments to show that air exerts pressure.

18. Why is the effect of great atmospheric pressure not felt by the man ?

19. Why do we require two holes in a milk tin before the milk can be poured out ?

20. How are you able to drink lemonade through a straw ?

21. The walls of the water reservoir are not of uniform thickness—the bottom parts are thicker than the upper parts. Explain why this is so.

22. If a person is standing close to a fast moving train, in which direction is he likely to fall—towards the train or away from it ?

23. State Bernoulli's principle for flow of fluids. Give two practical applications of this principle.

24. (*a*) What is meant by streamline flow and turbulent flow ?

(*b*) What happens to the speed of a fluid through a constriction (*i.e.*, narrow pipe) ?

25. What is capillarity ? Give some examples of capillarity in daily life.

26. Define surface tension.

Describe two experiments to illustrate the phenomenon of surface tension.

27. Explain the following :—

(*i*) Why water rises against gravity in a capillary tube ?

(*ii*) Why a small drop of mercury is almost perfectly spherical whereas a large drop resting on a glass plate is flat at the top ?

(*iii*) The small space between two parallel circular glass plates is filled with water. Explain why is it much easier to separate the plates by sliding over the other than by a direct pull.

(*iv*) Why does ink rise in a blotting paper ?

(*v*) Why does a small piece of camphor dance on the surface of water ?

28. Explain the lift of the wing of an aeroplane.

29. When an air stream is blown between two sheets of cards close to each other, they attract. Why ?

30. What happens to the pressure of a fluid when it passes through a region where its speed increases ?

31. Explain by what factor the rate of flow of water will increase if the diameter of the bore of the capillary is doubled.

32. What is a siphon ? Explain the principle on which it works. Mention some of its practical applications. [*A.I.S.S. 1987*]

33. In using a siphon to transfer petrol from one car tank into another; will the petrol flow if the two tanks are at the same level, one containing plenty of petrol while the other is empty ? Why does the liquid flow more quickly out of the siphon when the level of the mouth of the siphon is lower ?

34. Explain how it is possible to water plants in pots by placing a pail of water beside them and running threads of wool from the water to the soil.

35. Answer the following questions :

(*i*) Why is sandy soil dry, while clay soil is wet ?

(*ii*) Why can many insects walk over the surface of water without sinking ?

(*iii*) Why do the bristles of an artist's paint brush cling closely together when removed from water ?

36. Describe with the aid of diagrams how you would show that the rise of water in a capillary tube depends on the width of the tube.

37. State Hooke's law and describe briefly how it can be verified. [*A.I.S.S. 1986*]

A pointer attached to a spring points to 10 cm when there is no weight hanging from it. When a 20 *g* weight hangs from it, it points to 12·5 cm. Where does it point if an 80 *g* weight hangs from the spring ? What weight will be required to make the pointer point to 13·5 cm ?

38. How can you show experimentally that liquids send across pressure equally in all directions ?

39. How can you show very simply that the pressure in a liquid increases with depth ?

40. Fig. (2.48) is a tank of water. Why is the tap placed at the bottom ? As water is drawn from the tap, does it come out with the same force (or at the same rate) while the tank is emptying ? Explain.

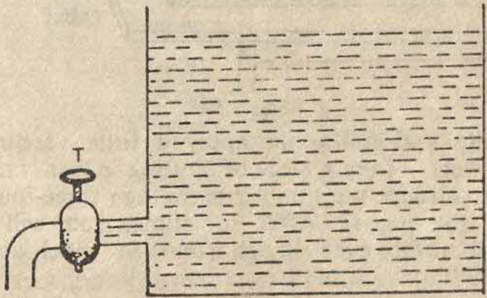


Fig. 2.48

41. Fig. (2.49) is a tank of water. Explain what happens when tap T is opened.

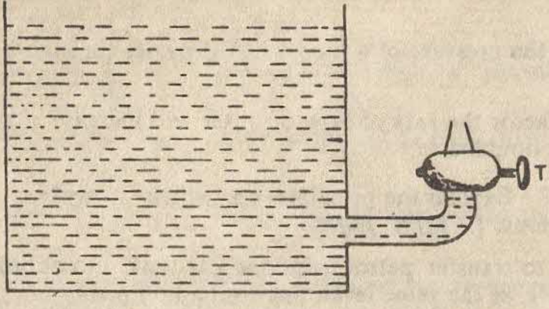


Fig. 2.49

42. In Fig. (2.35), A is a reservoir from which water is supplied to a town. B, C, D and E are houses supplied with water through pipes. Explain the following :

(*a*) In which of the four houses B, C, D and E will the water come out of the tap with the greatest force and why ?

(*b*) Which of them is most likely to have a continuous supply of water, whether the season is dry or wet ? Why ?

(*c*) Which of them is most likely to be short of water during the hot season when the water supply is generally low, and why ?

(*d*) Which of them will continue to have water for the longest time after the tap T of the reservoir has been closed, and why ?

43. Place two thick books on a table about 5 cm apart (Fig. 2.50). Place a sheet of paper on them, and blow hard between the books underneath the paper. The paper will bend towards the table. Explain why ?

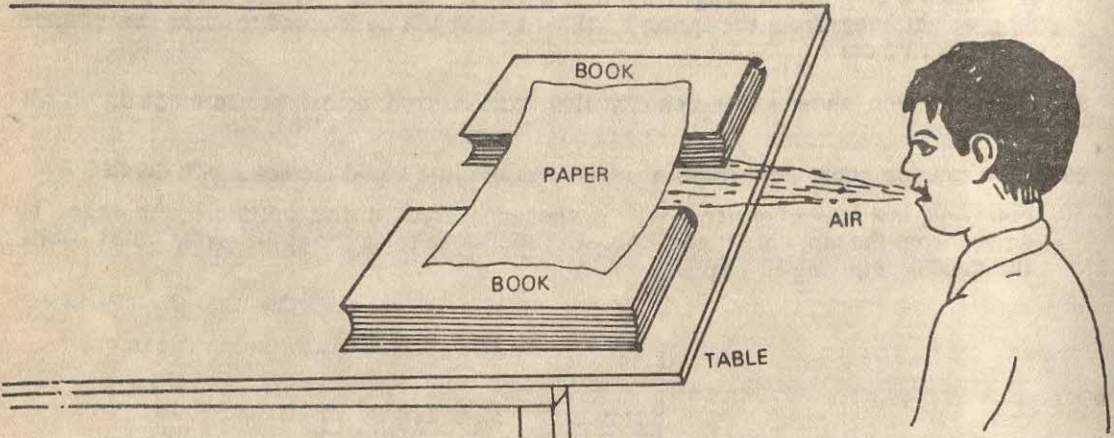


Fig. 2.50.

44. Take a sewing needle and uniformly apply a little vaseline to it (This prevents the needle from getting wet). Take a piece of blotting paper or a piece of newspaper and place it on the water surface in a tumbler more than three-fourths full of water. Gently place the needle on the paper. After sometime, you will find that the needle keeps floating on the water surface even though iron is so much denser than water. Explain why ?

45. An egg is found to sink in water. When salt is gradually dissolved in the water, the egg rises up and finally floats. Explain why ? [*A.I.S.S. 1987*]

PROBLEMS

1. A copper wire of length 2 m and diameter 2 mm is supported at one end and hangs vertically down. If it is loaded at the other end by a mass of 1 kg, calculate the extension of the wire. Young's modulus of copper$=1{\cdot}3\times10^{11}$ N/m^2.
[**Ans.** $4{\cdot}8\times10^{-5}$ m]

2. A load of 20 kg stretches a wire of length 4 m and area of cross-section 4 mm^2 by 0·004 m. Calculate the values of stress and strain. (Take $g=9{\cdot}8$ m/s^2).
[**Ans.** $4{\cdot}9\times10^7$ N/m^2 ; 10^{-3}]

3. Calculate the Young's Modulus of a wire 3 m long : 1×10^{-5} sqm in cross-section when a load of 10 kg stretches it by 0·1 mm. ($g=9{\cdot}8$ m/s). [**Ans.** $2{\cdot}94\times10^{11}$ N/m^2]

4. A wire of length 2m and $0{\cdot}5\times10^{-5}$ m^2 in cross-section is to be doubled in length. Calculate the force required if Young's Modulus of the wire is $9{\cdot}8\times10^{10}$ N/m^2. ($g=9{\cdot}8$ m/s^2).
[**Ans.** $4{\cdot}9\times10^5$ N]

5. A copper wire of length 5m has Young's Modulus as $1{\cdot}25\times10^{10}$ N/m^2. A stress of 15×10^{-3} kg wt per sq mm is applied on it. Calculate the strain and the extension produced in the wire. ($g=9{\cdot}8$ m/s^2). [**Ans.** $1{\cdot}18\times10^{-5}$; $5{\cdot}9\times10^{-5}$ m]

6. What force is required to stretch a steel wire of 1×10^{-4} sq m cross-section to double its length ? Y for steel$=2\times10^{11}$ N/m^2. [**Ans.** 2×10^7 N]

7. Following observations were made during an experiment for the study of the elasticity of a wire :

	Stress (in N/m^2)	**Strain**
1	0×10^6	0×10^{-3}
2	2×10^6	1×10^{-3}
3	4×10^6	2×10^{-3}
4	6×10^6	3×10^{-3}
5	$6{\cdot}5\times10^6$	$3{\cdot}25\times10^{-3}$
6	8×10^6	4×10^{-3}
7	1×10^7	5×10^{-3}

Plot a graph between stress and strain. Calculate the value of stress for strain $=2{\cdot}5\times10^{-3}$ from the graph. Also calculate 'Y' for the wire.
[**Ans.** 5×10^6 N/m^2 ; 2×10^9 N/m^2]

8. While studying the elasticity of wire experimentally following observations were made :

Sr. No.	**Load (in N)**	**Length of wire (in m)**
1	0·00	1·000
2	1·00	1·001
3	2·00	1·002
4	3·00	1·003
5	4·00	1·004
6	5·00	1·005
7	5·25	1·006
8	5·50	1·008
9	5·75	1·020
10	6·00	1·040

Plot a graph between extension of the wire and the corresponding load. Interpret the graph.

9. A log floats on water with $\frac{4}{5}$ its volume submerged. What is the density of the log ? Density of water$=10^3$ kg/m^3. [**Ans.** $0·80\times10^3$ kg/m^3]

10. Suppose a crown like the one Archimedes tested has a weight of 30N in air, and only 28N when submerged in water.

(*a*) Is it made of pure gold or some other material ?

(*b*) If the crown is made partially of lead and partially of gold, what is the percentage of lead in it ?

Density of gold$=19·3\times10^3$ kg/m^3 ; Density of lead$=11·3$ kg/m^3.
[**Ans.** (*a*) Not pure gold (*b*) 56% lead and 44% gold]

11. A sinker weighs 45 g in air and 25 g in water. Find its density Density of water $=10^3$ kg/m^3. [**Ans.** $2·25\times10^3$ kg/m^3]

12. A body weighs 75 g in air and 50 g in water. Find its volume [**Ans.** $2·5\times10^{-5}$ m^3]

13. A piece of metal weighs 100 g in air, 88 g in water. What would it weigh in a liquid of density $1·5\times10^3$ kg/m^3 ? [**Ans.** 82 g]

14. A man carries a 20 kg bucket full of water in his right hand and a 2 kg fish in his left hand. The density of fish is $1·0\times10^3$ kg/m^3. He puts the fish into the bucket of water. How much does the right hand carry ? [**Ans.** 20 kg]

15. An iceberg floats with $\frac{1}{10}$ of its volume above the surface in fresh water. What fraction will be above the surface in sea-water ? 1 m^3 of fresh water$=1000$ kg and 1 m^3 of sea water$=1025$ kg. $\left[\textbf{Ans.}\ \frac{31}{256}\right]$

16. A circus elephant weighing 2000 kg is taken aboard a barge of length 5 m and breadth 2 m which is standing in a river. How many metre does the barge sink ? Density of water$=10^3$ kg/m^3. [**Ans.** 0·2 m]

17. A copper cube of mass 0·50 kg is weighed in water (density 10^3 kg/m^3). The mass comes out to be 0·40 kg. Is the cube hollow or solid ? Density of copper$=8·96\times10^3$ kg/m^3. [**Ans.** hollow]

18. A piece of ice floats on water. What fraction of its volume will be above the surface of water ? Density of ice$=0·92\times10^3$ kg/m^3. [**Ans.** 0·08]

19. A cylindrical vessel of cross-sectional area 5×10^{-3} m^2 contains water to a depth of 0·02 m Find the force (thrust) on the base, and also the additional force (thrust) when a wooden block of volume 6×10^{-5} m^3 and density 500 kg m^{-3} floats on the surface of the water. Density of water is 1000 kg/m^3. [**Ans.** 1N ; 0·3 N]

20. A stone weighing 49·35 g appears to weigh 28·35 g when suspended in water. What will it appear to weigh in a liquid of density$=1·12\times10^3$ kg/m^3 ? Density of water $=10^3$ kg m^{-3}. [**Ans.** $25·83\times10^{-3}$ kg]

21. A rectangular barge 6 m long, 2 m wide and 1 m deep weighs 360 kg. When it is floating unloaded in water, where is the water line ? What is the greatest load which can be placed in it without its sinking ? The weight of 1 m^3 of water$=1000$ kg.
[**Ans.** 0·03 m immersed : 11640 kg]

22 Five shipwrecked sailors weighing on the average 80 kg each saved themselves on a raft 3 m$\times$2 m$\times$0·5 m

(*a*) The raft floated in the sea with its top face level with the surface. What was the weight of the raft ?

(*b*) They reached the coast and attempted to pass up a wide river. Did the raft sink ?

(*c*) If one man has volunteered to swim ashore, would the raft have sunk in the river then ?

Density of sea water $=1025\ \text{kg/m}^3$ & density of river water $=10^3\ \text{kg/m}^3$.
[**Ans.** (*a*) 2675 kg (*b*) Yes (*c*) No]

23. A body weighing 300 g in air was put in a vessel containing mercury and was found to float in it with 3/7 of its volume outside mercury. If the density of mercury be $13{\cdot}6\ \text{g/cm}^3$, find that of the body. Also determine its volume.
[**Ans.** $7{\cdot}77\ \text{g/cm}^3$; $38{\cdot}6\ \text{cm}^3$]

24. A boy weighing 40 kg is standing on the floor. The area of his foot is $1{\cdot}0\times10^{-2}\ \text{m}^2$. Calculate the pressure he exerts when he stands on one foot and on both feet. ($g=9{\cdot}8\ \text{ms}^{-2}$)
[**Ans.** $39200\ \text{N/m}^2$; $19600\ \text{N/m}^2$]

25. Calculate the pressure at the depth of 1/10 m in mercury. Density of mercury is $13{\cdot}6\times10^3\ \text{kg m}^{-3}$. What will be the pressure, if it is water ? Density of water $=10^3\ \text{kg m}^{-3}$.
[**Ans.** $13328\ \text{N/m}^2$; $980\ \text{N/m}^2$]

26. Find the height of a column of water which would produce the same pressure on the earth as is produced by the earth's atmosphere. Atmospheric pressure is $1{\cdot}01\times10^5$ *Pa* (or N/m^2). Density of water $=10^3\ \text{kg/m}^3$.
[**Ans.** $10{\cdot}3$ m]

27. Calculate the order of magnitude of the force exerted by the earth's atmosphere *i.e.*, $1{\cdot}01\times10^5\ \text{N/m}^2$ on the outside of a person's body having surface area $2{\cdot}2\ \text{m}^2$. Why does such a force cause no discomfort to the person and produce no acceleration ?
[**Ans.** $2{\cdot}2\times10^5$N]

28. A mercury manometer (a device used to measure pressure, usually the difference between the pressure on a confined gas and atmospheric pressure) is connected to a gas cylinder. The mercury column connected to the cylinder falls to a point 18 cm below the top of the other mercury column.

(*a*) What is the gauge pressure of the gas in the cylinder ?

(*b*) What is its absolute pressure ?

Density of mercury $=13{\cdot}6\times10^3\ \text{kgm}^{-3}$; $g=9{\cdot}8\ \text{m/s}^2$.

Atmosheric pressure $=1{\cdot}01\times10^5\ \text{N/m}^2$ [**Ans.** (*a*) $0{\cdot}24\times10^5\ \text{N/m}^2$; (*b*) $1{\cdot}25\times10^5\text{N/m}^2$]

29. A patient's systolic pressure is 130 mm Hg. What is this pressure in SI units ? Atmospheric pressure is 76 cm Hg and density of mercury is $13{\cdot}6\times10^3\ \text{kg m}^{-3}$. (Take $g=9{\cdot}8\ \text{N/m}^2$).
[**Ans.** $1{\cdot}73\times10^4\ \text{N/m}^2$]

30. A storage dam is filled upto a height of 250 metre. What is the pressure at the bottom ?
[**Ans.** $24{\cdot}5\times10^5\ \text{N/m}^2$]

31. Consider a metallic cube of side 5 cm held in water. The top face of the cube is at a depth of 10 cm below the surface. Calculate :

(*a*) The total force on the upper surface and its direction.

(*b*) The total force on the bottom surface and its direction.

(*c*) The force exerted by the liquid on this body and its direction.

(*d*) The tension on the string required to hold it if its mass is 1 kg.

(*e*) The apparent loss in weight

[**Ans.** 245000 dyne (downward) ; 367500 dyne (upward) ; 122500 dyne (upward) ; 980000 dyne ; 857500 dyne]

32. A cubical tank, whose sides are 8 m, is filled with water. Find the force on the bottom and on one of the sides. Density of water is $10^3\ \text{kg/m}^3$ and $g=0{\cdot}8\ \text{m/sec}^2$.
[**Ans.** 5017600 N ; 2508800 N]

33 Water is supplied to a house from a reservoir 1000 m above sea level. Find the pressure in a pipe at the top of a house 400 m above sea level. **[Ans** $58{\cdot}8\times10^{4}$ N/m^{2}]

34. The pressure at a water tap at the base of a building is 3×10^{6} dyne/cm^{2} and on its top it is $1{\cdot}6\times10^{6}$ dyne/cm^{2}. Find the height of the building. **[Ans.** 14·28 m]

35. Calculate the pressure due to a column of mercury 1 metre high ; given that density of mercury is $13{\cdot}6\times10^{3}$ N/m^{2} and $g=9{\cdot}8$ m/sec^{2}. **[Ans.** 133280 N/m^{2}]

36. Calculate the difference of pressure between two points 1000 m apart lying on the same vertical line in fresh water. **[Ans.** 98×10^{5} N/m^{2}]

37. If the height of a mercury barometer be 76 cm., find the atmospheric pressure in dyne/cm^{2} and newton/m^{2}. **[Ans.** $1{\cdot}013\times10^{6}$ dyne/cm^{2}, and $1{\cdot}013\times10^{5}$ N/m^{2}]

38. A dock gate is 15 m wide and the water outside stands at a height of 10 m above the bottom of the dock gate. Calculate the force upon the gate. **[Ans.** $7{\cdot}35\times10^{7}$ N/m^{2}]

39. A rectangular tank 6 m long, 3 m broad, and 2 metre deep is filled with water. Calculate the force on the bottom and on each of the sides.
[Ans. $3{\cdot}53\times10^{5}$ N ; $5{\cdot}88\times10^{4}$ N ; $1{\cdot}18\times10^{5}$ N]

40. (*a*) Which would exert a greater pressure ; a column of water 20 cm high or a column of mercury 1·5 cm high ?

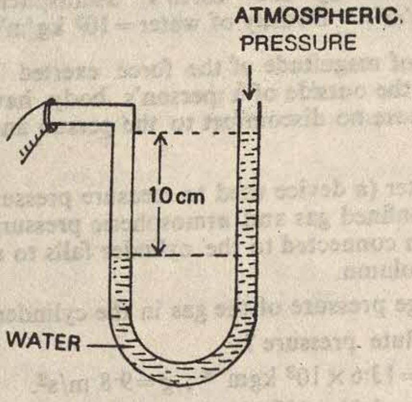


Fig. 2·51

(*b*) Suppose a water manometer (Fig. 2·51) shows a 'head of water' of 10 cm and the atmospheric pressure is 76 cm of mercury, what is the total pressure in *cm* of *water*. Density of mercury = 13·6 g/cm^{3}. **[Ans.** 1043·6 cm of water]

41. In a normal adult at rest the average speed with which the blood flows through the aorta, the main artery leading from the heart is 0·33 m/s.

(*a*) If the aorta has a cross-sectional radius of about 1·0 cm, how much blood flows per second through the aorta ?

(*b*) If the total cross-sectional area of all the other arteries fed by the aorta is 20×10^{-4} m^{2}, at what speed does blood flow in these arteries ?
[Ans. (*a*) $1{\cdot}0\times10^{-4}$ m^{3}/s ; (*b*) 0·05 m/s]

42. The amount of water flowing out of a water pipe in 1 min is 0·54 m^{3}. If the pipe has a radius of 6·0 cm, what is the average speed of the water flowing in the tube ?
[Ans. 0·080 ms^{-1}]

43. A horizontal pipe has a constricted area where the diameter is reduced from 8·0 to 2·0 cm. In the 8·0 cm portion of the pipe the speed of water flow is 2·0 m/s and the pressure is $6{\cdot}5\times10^{5}$ *Pa*. What is the speed of flow in the 2·0 cm portion of the pipe ?
[Ans. 32 m/s]

CHAPTER 3

Waves

3.1. INTRODUCTION

In class IX, linear motion and circular motion were considered. Another common type of motion is the *to and fro repeating movement about a mean position called a* **vibratory** *motion* or an **oscillatory** *motion.* Examples of oscillatory motion are provided by swinging pendulum, a balance wheel of a watch, a mass on the end of a vibrating spring ; the strings and air columns of musical instruments when producing a note. Sound waves are transmitted by the oscillation of the particles of the medium in which the sound is travelling. We also believe that atoms in a solid vibrate about their fixed positions. Engineers as well as scientists need to know about vibrations. They can occur in turbines, aircraft ; cars ; tall buildings etc. In this chapter, we shall study how the cooperative vibratory motion of a collection of particles can cause continuous disturbance to propagate. We call this disturbance a *wave.* We shall learn some basic characteristics of waves and wave propagation.

Nearly every vibrating body sends out a wave. Have you ever stopped to think when you are watching television that everything you see and hear was transmitted to you from the station by waves ? The station generated electromagnetic waves by vibrating electrical charge in an antenna. Your TV set responded to these waves and generated light and sound waves, which then travelled across the room to you.

We know that some mechanism must be provided to transport energy from one point to another. The place where energy is available is often different from the place where it is needed. A more interesting, but more complicated way of transporting energy involves waves. The basic concept in our use of the term *wave* is that the wave involves some quantity or disturbance which changes in magnitude with respect to time at a given location and changes in magnitude from place to place at a given time. The common characteristic of all types of waves is that energy is transferred by the wave without the transport of matter.

In this chapter we shall learn the general rules about how waves behave. We shall find that there are two general types of waves into which all mechanical waves can be divided. A considerable portion of physics is devoted to the study of their behaviour.

Fig. 3.1.

3.2. WAVE MOTION

If anyone is asked to produce an everyday example of wave motion, almost the only ones that come to mind are ripples running over the surface of water or the large scale effects of waves at sea (Fig. 3.1).

Throw a piece of stone into a quiet tank of water. Circular ripples are formed and travel outwards from the point where the stone struck the surface of water. Let us see the mechanism

by which these ripples have been formed. As soon as the stone strikes the surface of water, a depression is caused. Due to elasticity, water tries to recover its original level and in doing so fills up the depression. Owing to inertia and hence kinetic energy of its particles, the water overshoots its mean position. This results in the formation of an elevation which is again followed by a depression and so on. Due to cohesion (*i.e.* force of attraction between molecules of water), the neighbouring particles are also affected though a little later. Thus a wave train of elevations followed by depressions is formed. A piece of cork thrown on the surface of water will simply toss up and down when the ripple reaches it. It would, therefore, be clear to a careful observer that it is the disturbance which eventually reaches some distant part of the water tank and produces physical effects there, even though there is no actual transfer of water from the point of impact of the stone to the distant point.

Another easy way to produce wavemotion is to tie one end of a long rope to a window bar or a hook on the wall. If the free end is moved up and down, the disturbance will be seen to travel along the rope (Fig. 3.2).

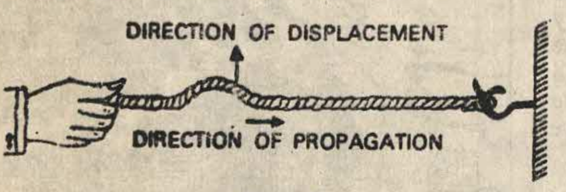


Fig. 3.2

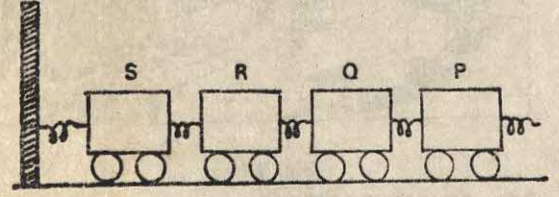


Fig. 3.3

Imagine a system of trolleys linked together by springs. The spring attached to the last trolley *P* is pulled (Fig. 3.3) and then released immediately. It will be observed that the trolley *Q* will move to the right, followed by trolleys *R* and *S* and so on. Thus a disturbance started at one end travels to the other end.

In each of the above mentioned examples, the observer has observed that there is a moving disturbance. This moving disturbance is a *wavemotion* or a *wave*.

Wave Motion *may, therefore, be defined as a form of disturbance which travels through an elastic material medium and is due to the repeated and periodic motion of the particles of the medium about their mean position, the motion being handed over from particle to particle.*

Let us see, from the above mentioned examples, what common features of a wavemotion are : A *disturbance* started at one place progressively moves along. That is why such a wavemotion is also called a progressive wavemotion. The progressive movement takes place *through a medium* ; for example water, rope and springs in the above three cases. Notice that although the disturbance travels from one region of the medium to another, no part of the medium travels very far from its mean position.

Thus for a wavemotion :

(*i*) A material and elastic medium is necessary.

(*ii*) The particles of the medium do not travel forward but simply vibrate about their mean positions.

(*iii*) A particle of the medium begins to vibrate a little later than its preceding particle.

(*iv*) The velocity of the wavemotion is different from the velocity of the vibrating particle of the medium.

If we are concerned with waves travelling in a material substance, a medium composed of matter *e.g.* water, rope, springs, etc., then we call these waves as mechanical waves.

A wave of limited length is called correctly a *wave train* or *wave group*. It is distinguished from a *continuous wave*, which has neither beginning nor end—and is of course a product of a physicists' imagination ! and a *pulse* which does not contain any *repeated* up-and-down motion. A pulse is a wave set up by a single disturbance *e.g.* dropping a stone in a pond ; sound waves produced by clapping of hands.

Wave Energy. **As a wave train passes over the surface of water, it does not carry the water with it. This can be seen by placing a few pieces of some light material such as cork on the surface of water. As the wave passes them, they merely bob up and down. The wave carries *energy* setting the water in motion—the wave is indeed nothing more than**

the up-and-down of the water, conveyed to one patch by the movement behind it, nearer to the source, and then passed on to the next patch in front, farther away from the source. ***In this way a wave transfers energy without transferring matter.*** This property of waves uniquely distinguishes waves from other methods by which energy can be transferred.

A proper understanding of waves is essential to anyone investigating communication, whether by speech, radio or television; how we see; how we can make images; what is colour; how musical instruments work; how we navigate; and even why atoms are as they are. How is it that waves are so important and yet so uncommon in our day-to-day experiences. It is because wave-motion serves as an important *model* when we try to understand so many different aspects of the physical world. Light, radio, sound, even electrons in some of their properties, ***behave*** in the way waves behave. We cannot see what it is that 'waves'—as we can with the water on the surface of a lake—but then we cannot ***see*** the tiny particles which make up a gas. We accept models because they provide an explanation of what we *can* observe.

3.3. EXAMPLES OF WAVE-MOTION

Most of the wave-motions with which we are familiar involve a large-scale co-ordinated disturbance of many particles or objects. While the individual particles do not move far, the disturbance may travel great distances, carrying with it energy and momentum. The motion of the particles very with the type of wave. Some of the examples of wave motion are given below.

(*i*) *Sound wave.* In a sound wave, the molecules move back and forth.

(*ii*) *A wave on a string*. In a wave on a string, the parts of the string move up and down (Fig. 3.2).

(*iii*) *Light waves* Are also co-ordinated disturbances involving changing electric and magnetic fields. Here, no particles move, but the waves nevertheless carry energy and momentum and the mathematical description of these waves is nearly identical to the mechanical examples given above.

(*iv*) Up and down motion of a weight hanging on a spring (Fig. 3.4).

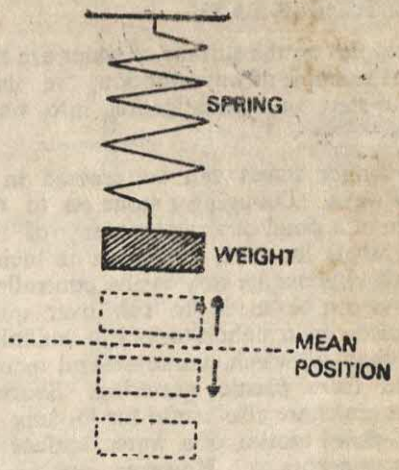


Fig 3.4

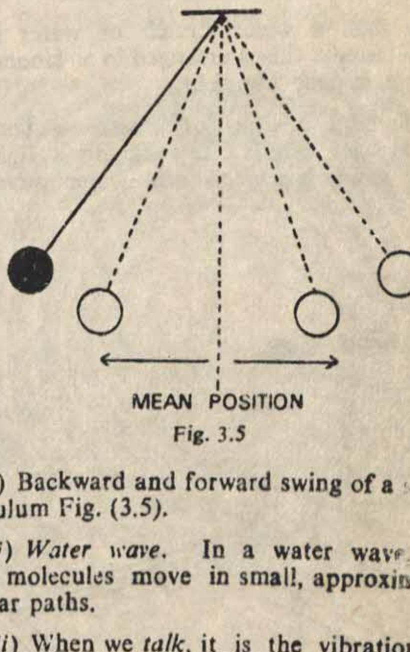


Fig. 3.5

(*v*) Backward and forward swing of a simple pendulum Fig. (3.5).

(*vi*) *Water wave.* In a water wave, the water molecules move in small, approximately circular paths.

(*vii*) When we *talk*, it is the vibrations of our 'vocal cord' inside the throat that produce sound wave (Fig. 3.12).

Sound is produced by making things vibrate in a medium (air). When one strikes a drum, one can hear the sound, but one may not be able to see the vibrations of the membrane. Similary when one plays on a *table*, one can hear sound and one may be able to observe the vibrations of the membrane by placing a few small pieces of cork on it which will be found jumping up and down.

3.4. THE RIPPLE TANK

Since ripples on the surface of water are the commonest example of wave motion, we shall use them to start our investigation into wave behaviour.

Water-surface waves can be created in a number of ways. Dropping a stone on to the still surface of a pond can create many of the effects we shall look at, but waves on such a large stretch of water are not easily controlled. Water waves can be made to run over quite long distances in a laboratory by confining them to a channel, which can be several metres long made from plastic guttering. Shorter, transparent tanks are also useful for looking at the up-and-down motion of a water surface as a wave passes across it. However, neither of these lets us look at a wave spreading out into the space around it—as it does on a pond.

To do this, a wider stretch of water is required. Usually this is arranged in a laboratory in a *ripple tank* (Fig. 3.6).

A ripple tank consists of a shallow tank with a glass base Fig. [3.6 (*a*)] having a light bulb above it which projects any water waves produced in the tank on to a white screen (*e.g.*, drawing sheet or a piece of hard board painted white) lying under the tank on the floor or the bench [Fig. 3.6 (*b*)]. The tank is filled with water to a depth of about 1·5 cm. A ripple or a pulse in the tank can be produced by dipping a finger or a pencil into the water or by allowing a water drop to fall into it. Continuous pulses or waves of any shape, straight or circular are produced in the ripple tank by using a vibrator. A small variable speed motor can be made to vibrate a thin rod up and down to serve as a point source to produce *circular* waves [Fig. 3.6 (*d*) and Fig. 3.7 (*d*)]. We can also use *L*-shaped metallic wire with a spherical bob to produce circular waves. The motor can also be used to vibrate a horizontal straight stick so as to produce *straight* waves [Fig. 3.6 (*c*) and Fig. 3.7 (*c*)].

A shielded lamp is adjusted a little above the tank to act as a source of light. Those parts of the screen in line with the elevations of the water wave produced by an oscillating rod are bright, where as parts in line with the depressions are dark. The wave is then seen on the screen as a series of alternate black and white circular bands [Fig. 3.6(*d*)] centred on the

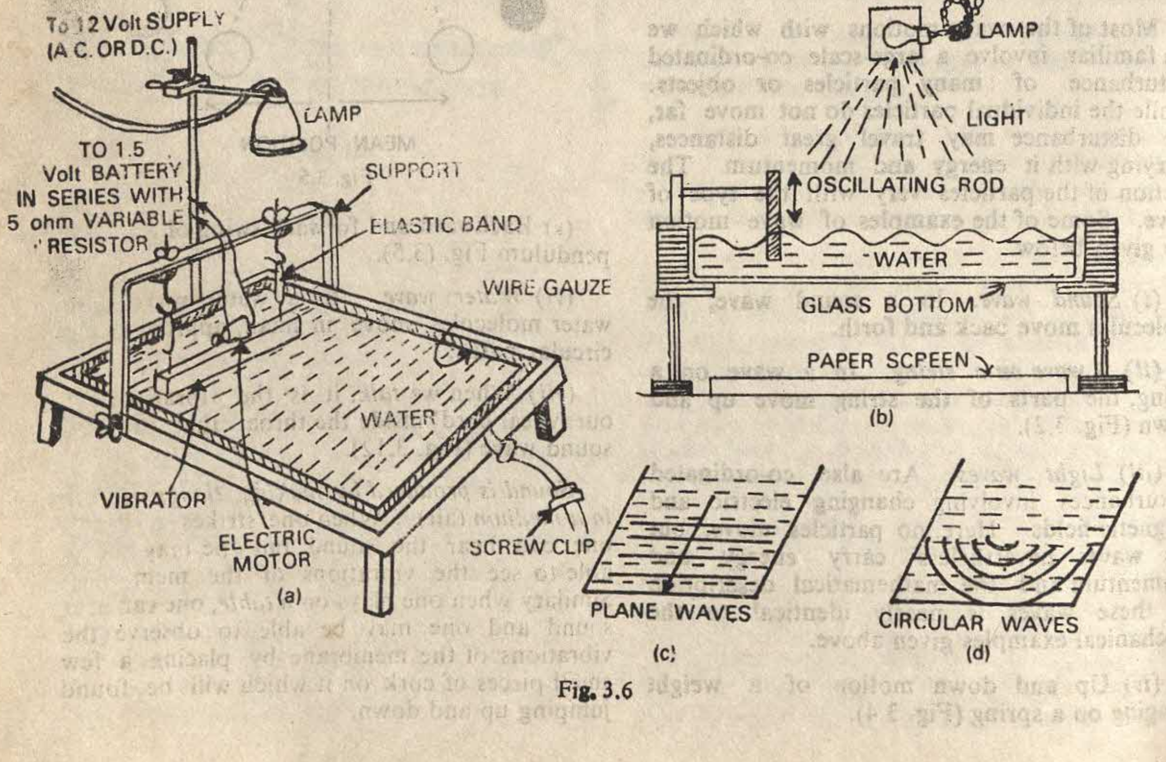
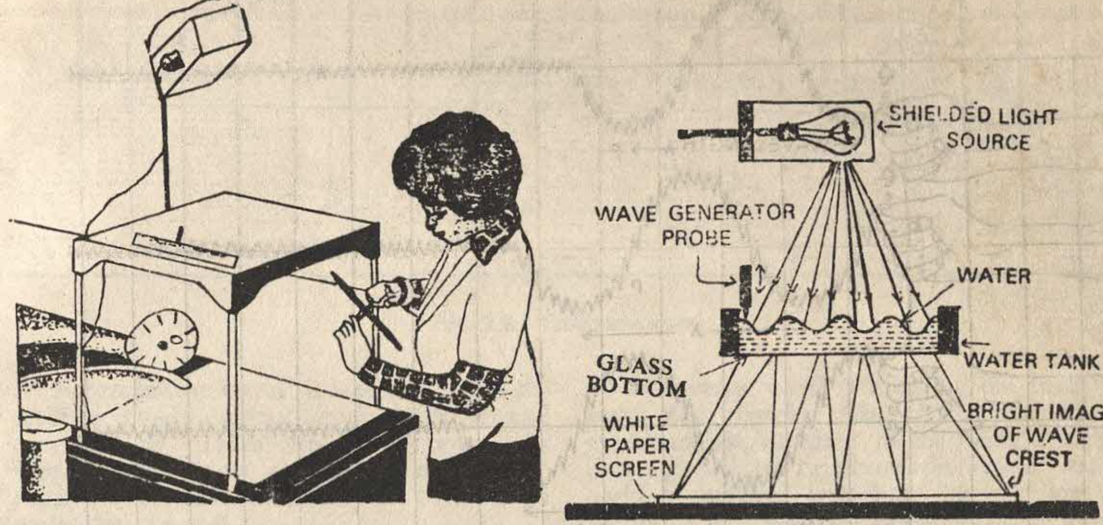
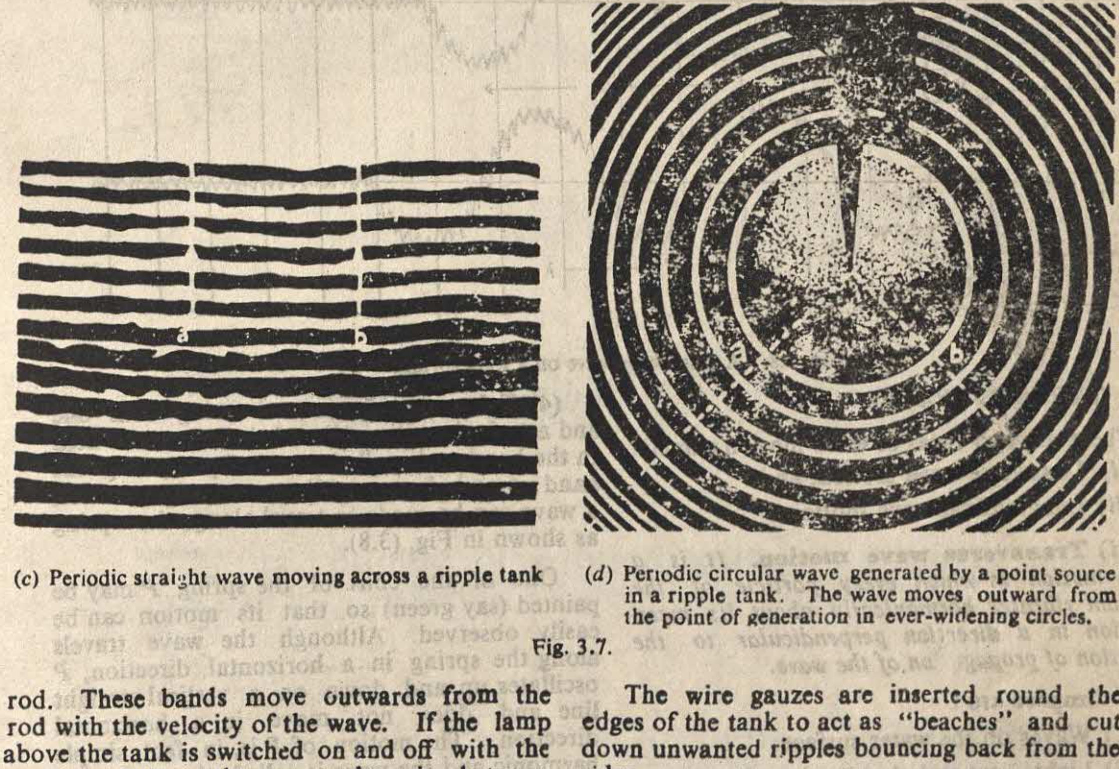


Fig. 3.6



(*a*) Ripple Tank

(*b*) A functional diagram of a ripple tank



(*c*) Periodic straight wave moving across a ripple tank

(*d*) Periodic circular wave generated by a point source in a ripple tank. The wave moves outward from the point of generation in ever-widening circles.

Fig. 3.7.

rod. These bands move outwards from the rod with the velocity of the wave. If the lamp above the tank is switched on and off with the same period as the wave, then in between flashes of light one elevation (crest) has just enough time to move into the position originally occupied by the crest a head of it. The bands of light then appear to be stationary.

The wire gauzes are inserted round the edges of the tank to act as "beaches" and cut down unwanted ripples bouncing back from the sides.

The properties of waves and a number of phenomena characterizing waves can be very conveniently demonstrated with a ripple tank.

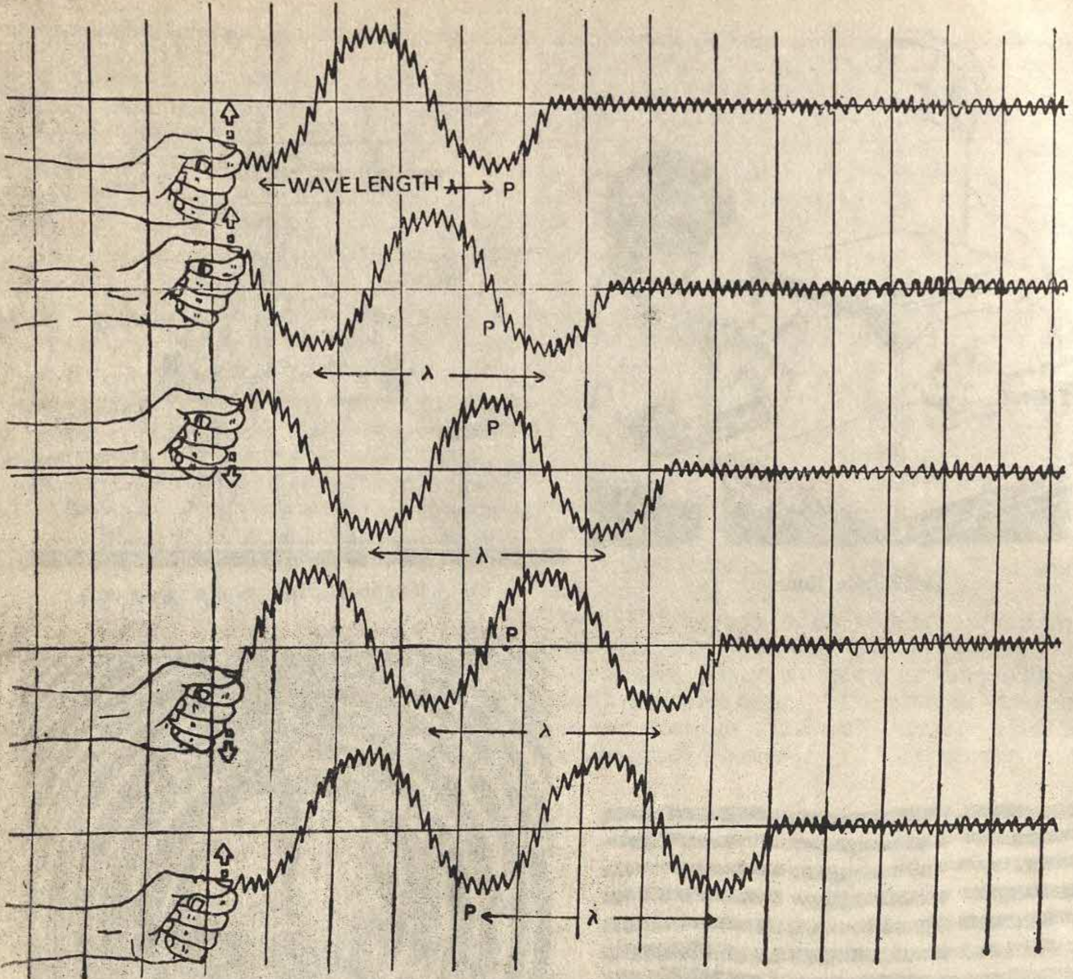


Fig. 3.8. A transverse wave on a long spring.

.5. TYPES OF WAVES

There are two types of wave motion namely

(*i*) Transverse wave motion, and

(*ii*) Longitudinal wave motion.

(*i*) Transverse wave motion. *It is a vave motion in which every particle of the nedium vibrates harmonically about its mean osition in a direction perpendicular to the irection of propagation of the wave.*

Examples are :

(1) Waves on the water surface.

(2) Light, heat and electromagnetic waves.

(3) Vibration of a string under tension in a nusical instrument *e.g.*, a sitar ; a guitar ; a iolin etc.

(4) Take a long horizontal spring with one and attached to the wall and the other end held in the hand and pulled taut. By moving the hand up and down rapidly two or three times, a wave can be made to travel along the spring as shown in Fig. (3.8).

One of the coils of the spring *P* may be painted (say green) so that its motion can be easily observed. Although the wave travels along the spring in a horizontal direction, *P* oscillates up and down on a vertical straight line and does not move in a horizontal direction. The motion of *P* is, in fact, simple harmonic and the wave is called the transverse wave since the oscillatory motion of any part of the system, such as *P*, is at right angles to the direction in which the wave is travelling.

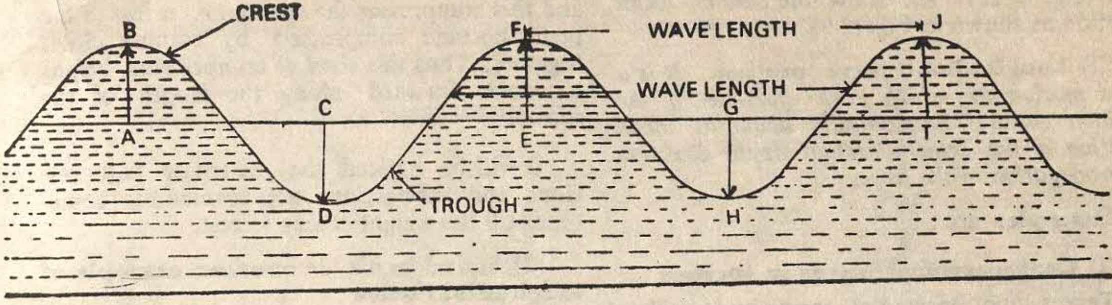


Fig. 3.9. Transverse wave

For transverse waves it is essential that the medium should possess *inertia, elasticity* and *also cohesion*. Transverse waves cannot be propagated in gases as they do not possess cohesion (*i.e.* force of attraction between the molecules of gases).

Transverse wave travels in the form of *crests* and *troughs*. Crest is the position of maximum displacement in the positive direction (*e.g. B, F, J*) *i.e.* above the line of mean position whereas trough is the position of maximum displacement in the negative direc-

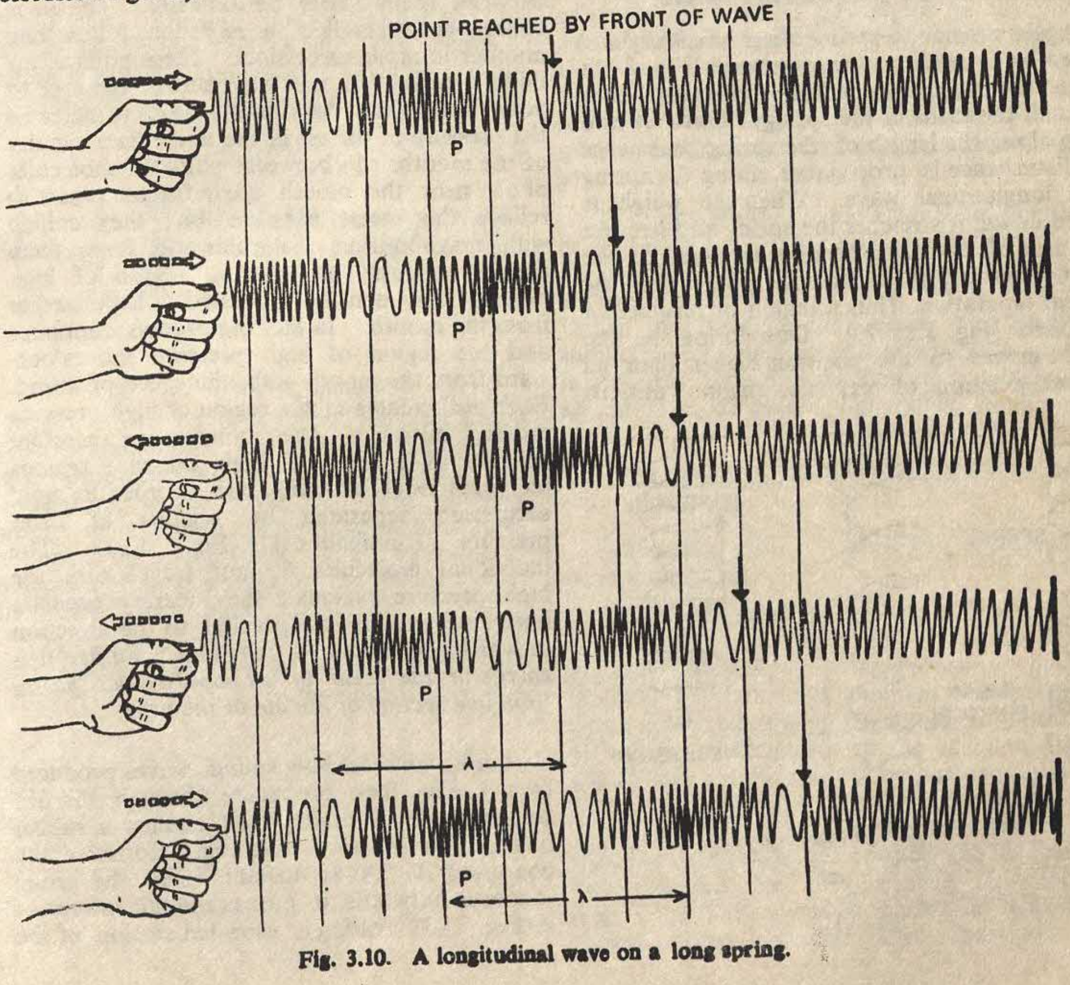


Fig. 3.10. A longitudinal wave on a long spring.

tion (*e.g. D, H*) *i.e.*, below the line of mean position as shown in Fig. (3.9).

(*ii*) **Longitudinal wave motion.** *It is a wave motion in which each particle of the medium vibrates harmonically about its mean position in the same directian as the direction of propagation of the wave.*

Examples are :

(*i*) **Compressional waves in springs** :

Take a long horizontal spring and oscillate its free end backward and forward in a horizontal direction (Fig. 3.10). The spring remains straight, but a wave of alternating compressions and extensions travels along its length. The painted (say green) coil *P* performs simple harmonic motion in a horizontal direction. The oscillatory motion of a part of the system is in the same direction that the wave is travelling and so this is a **longitudinal wave.**

Again consider a spring hung vertically and loaded by a weight at the lower end (Fig. 3.11). When the weight is pulled down and then released, the turns of the spring vibrate up and down along the length of the spring and hence the disturbance is propagated along the spring as a longitudinal wave. When the weight is pulled down, it stretches the spring and hence a few turns of the spring become extended or the distance between them becomes greater than the normal separation. Thus a region of *rarefaction* is caused [Fig. 3.11 (*b*)]. Due to inertia, the weight moves to the position higher than its normal position of rest (*i.e.* mean position) and this compresses the spring *i.e.* a few of the turns become compressed by coming closer together. Thus this state of compression begins to move forward along the length of the spring.

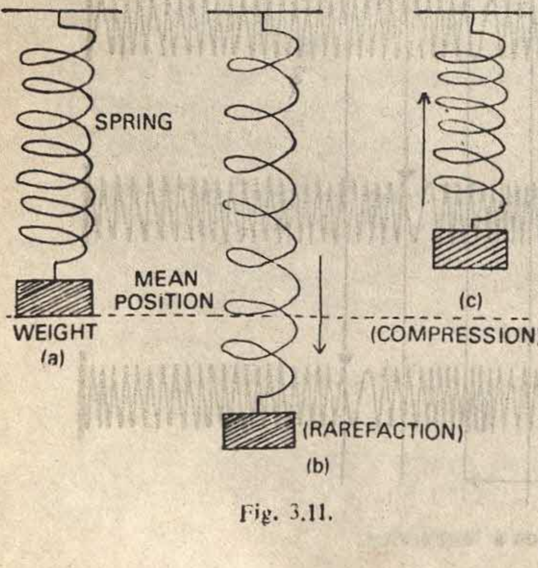


Fig. 3.11.

It will be noticed that alternate compressions and rarefactions are formed for sometimes till the weight comes to rest.

(2) **Sound in air is another example of longitudinal wave**

Sound is usually transmitted as a longitudinal wave in the air. Consider what happens when you shout to your friend across a lake. Air is expelled from your lungs through your windpipe, past two elastic membranes, known as vocal cords, inside the windpipe (Fig. 3.12). The flow of air past the vocal cords causes them to vibrate, and the size of the opening, between them varies periodically. The air is consequently expelled in *puffs* that follow one another in rapid succession. These puffs of air do not travel all the way across the lake to your friend's ear. As a puff emerges it increases the pressure of the air in the immediate vicinity of the mouth. In between puffs the molecules of air near the mouth move further apart to relieve the excess pressure, but they collide with neighbouring molecules and force them closer together so that a region of high pressure and density is created a little farther from the mouth. In fact the process continues and the region of high pressure moves outward from the mouth with the speed of sound. Each puff creates such a region of high pressure moving outward. The sound wave therefore consists of a train of high pressure regions (compressions) following one another in rapid succession separated by regions of lower pressure (rarefactions) (Fig. 3.12). The individual molecules do not travel with the high pressure regions : they merely oscillate backward and forward parallel to the direction in which the sound is travelling. *Rather it is energy in the form of an impulse that passes from one section of the air to the next.*

Let us consider how sound waves produced by a tuning fork propagate through the air. As you strike a tuning fork against a rubber pad, its prongs start vibrating. Consider say one prong *A*. At an instant when the prong *A* moves outwards, it pushes the air infront of it (Fig. 3.13) creating a crowded section of the

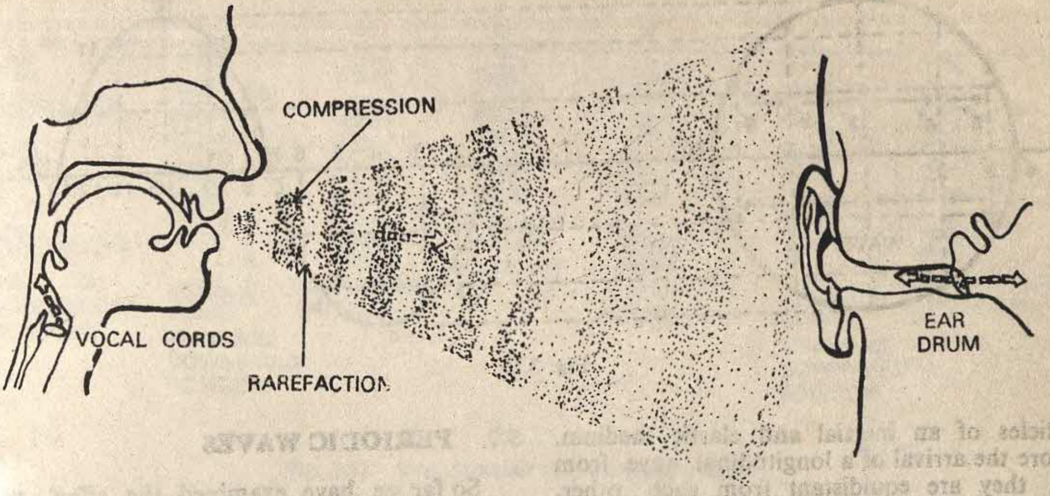


Fig. 3.12. Sound wave in air

air particles. The part pushes the air next to itself a little further and so on. This crowded section is called a compression. As the vibrating prong *A* moves to the otherside, it creates a region where the air is rarer. This section is called a rarefaction. The vibrating tuning fork keeps producing alternate compressions and rarefactions, which move out. This moving pattern of alternate compressions and rarefactions is the sound wave. The behaviour of molecules of air is similar to the behaviour of the coils of the spring in Fig. (3.10).

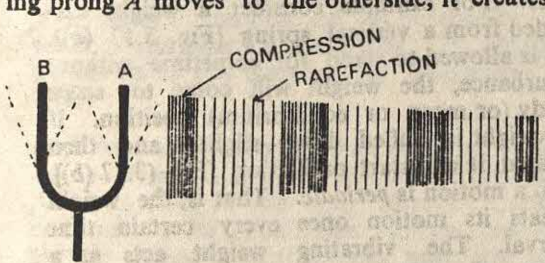


Fig. 3.13. Vibrating tuning fork

Longitudinal waves travel in the form of *compressions* (or *condensations*) and *rarefactions* (Fig. 3.14). Compression is a region of greater density *i.e.* the region in which the particles of the medium come nearer together than their normal separation whereas rarefaction is a region of smaller density of the medium *i.e.* the region in which the particles of the medium are farther than their normal separation.

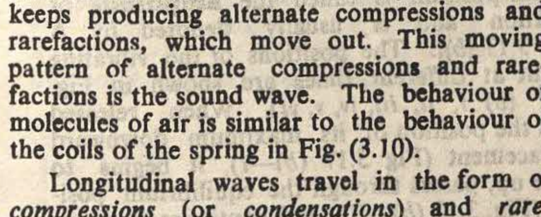


Fig. 3.14.

In a longitudinal wave, due to alternate compressions and rarefactions, the volume of the region of the medium is altered and as such volume elasticity is involved in the process. Hence for longitudinal waves, the medium should possess inertia and elasticity only. That is why this typeof wave motion is possible in all the type of media *i.e.*, solids, liquids and gases.

3.6 GRAPHICAL REPRESENTATION OF A WAVE

It is very useful to learn to represent a wave graphically.

Let us first take the case of a longitudinal wave. Particles in the region of compression are in the process of moving forward in the direction of the wave whereas the particles in the region of rarefaction are in the process of moving backward. If the forward displacements are represented by positive ordinate above the straight line and the backward displacements by negative ordinates below that line, the join of the ends of the ordinates will represent the displacement-time curve (Fig. 3·15). This curve is known as sine (or cosine) curve. Imagine that there are 13

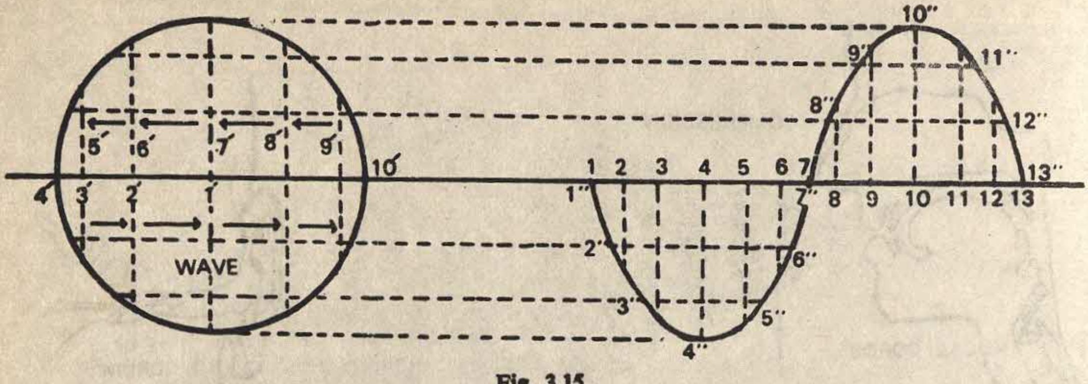


Fig. 3.15

particles of an inertial and elastic medium. Before the arrival of a longitudinal wave from left, they are equidistant from each other. Their relative positions are shown by 1, 2, 3... etc. (Fig. 3.15). When a longitudinal wave arrives from left, the particles are disturbed from their mean positions. After one time period their positions are shown by 1′, 2′, 3′... etc. Representing the displacements to the right by positive ordinates, those to the left by negative ordinates and joining their extremities 1″, 2″, 3″, ... etc., we get the required displacement-time curve. For a longitudinal wave, we can also get a similar curve by plotting the *density* of air (or medium) at any instant as a function of distance from the source (Fig. 3.16).

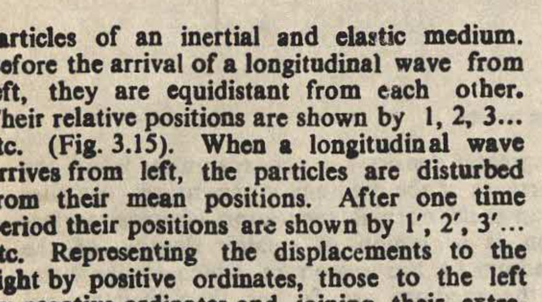
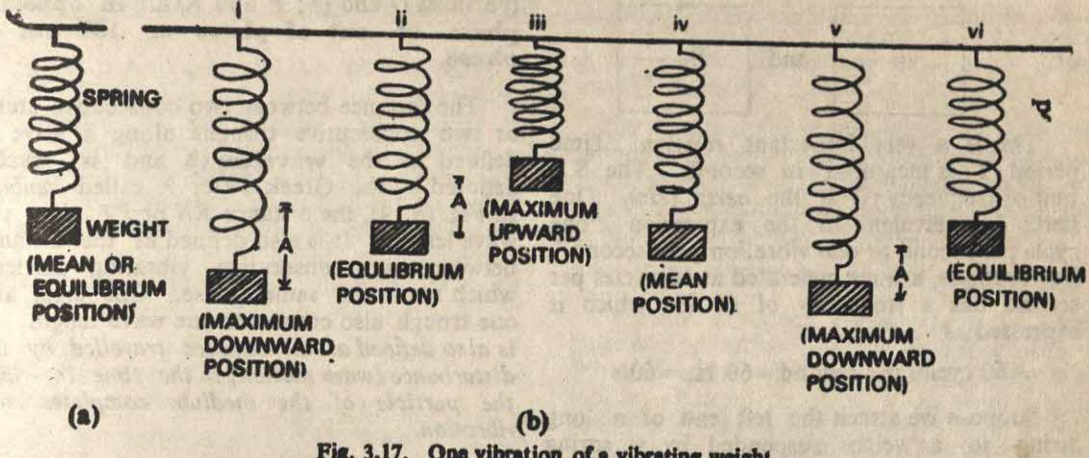


Fig. 3-16. Density-distance graph for a longitudinal wave

For the transverse wave, we plot at any instant of time, the displacement of different particles from the equilibrium position. We again get a curve similar to the one shown in Fig. (3.15) or Fig. (3.16).

3.7. PERIODIC WAVES

So far we have examined the effect of a single, non recurring wave disturbance. Now let us consider what happens if similar disturbances are repeated periodically. Regular, rhythmic disturbances resulting from continuing periodic vibrations are called *periodic waves*. For example consider a weight suspended from a vertical spring [Fig. 3.17 (*a*)]. If it is allowed to stand for sometime without disturbance, the weight will come to some steady (or mean or equilibrium) position. If the weight is pulled down slightly and then released, it will start oscillating [Fig. (3.17 (*b*)]. Such a motion is *periodic*. That is, the weight repeats its motion once every certain time interval. The vibrating weight acts as a source of periodic disturbances. The maximum displacement of the centre of the vibrating weight on either side of its mean or equilibrium position is called the **amplitude** of vibration and is usually denoted by A [Fig. 3·17 (*b*)]. The positions of the vibrating weight at different times are shown in Fig. (3·17 (*b*) *i*, *ii*, *iii*, *iv*, *v*, *vi*). When released from the position of its maximum downward displacement (Fig 3.17 (*b*)—*i*), it begins to move up, passes through the equilibrium position (Fig. 3.17 (*b*)—*ii*), and continues to move up due to inertia. The upward motion stops when the displacement from the equilibrium position becomes equal to A (Fig. 3.17 (*b*)—*iii*). The weight will now start moving down again, passes through the equilibrium or mean position (Fig 3.17 (*b*)—*iv*) and stops when the downward displacement is A again [Fig. 3.17(*b*)—*v*)]. This motion will go on repeating if there is no friction.


i
ii
iii
iv
v
vi
SPRING
WEIGHT
(MEAN OR EQUILIBRIUM POSITION)
A
(MAXIMUM DOWNWARD POSITION)
A
(EQULIBRIUM POSITION)
(MAXIMUM UPWARD POSITION)
(MEAN POSITION)
A
(MAXIMUM DOWNWARD POSITION)
(EQUILIBRIUM POSITION)

(a) (b)

Fig. 3.17. One vibration of a vibrating weight

When the weight starting from the maximum downward displacement (Fig. 3·7 (*b*)—*i*), goes up and comes back to the same position (Fig. 3·7 (*b*)—*v*), we say that the vibrating weight has completed one vibration. One can define one vibration with reference to any point along the motion and not necessarily the point of maximum displacement. In general, we can define one vibration (or oscillation) as follows :

Whenever a vibrating particle moves from its equilibrium position to one of its extreme positions, then to the other extreme position and back to its equilibrium position, we say that the vibrating particle has completed one vibration (or oscillation).

Thus when the vibrating weight in [Fig. 3·17 (*b*)] passes through the equilibrium position (or any reference point) twice *travelling in the same direction*, we say that one vibration or one oscillation has been completed.

In Fig. (3·18) we have plotted the displacement of the centre of the weight as a function of time. This is a sine curve (or a cosine curve). We always get such type of curves when we consider vibrating bodies. From Fig. (3·18), it is easy to see that one vibration is completed in each of the following :

OPQRS ; PQRST ; HPKQRSL.

***The time taken by a vibrating body to complete one vibration is called its* time-period *(T). The number of vibrations per second is called its* frequency and is denoted by ν (Greek letter nu).**

Time period (*T*)

$$= \frac{1}{\text{number of vibrations per second } (\nu)}$$

or $$\boxed{T\nu = 1}$$

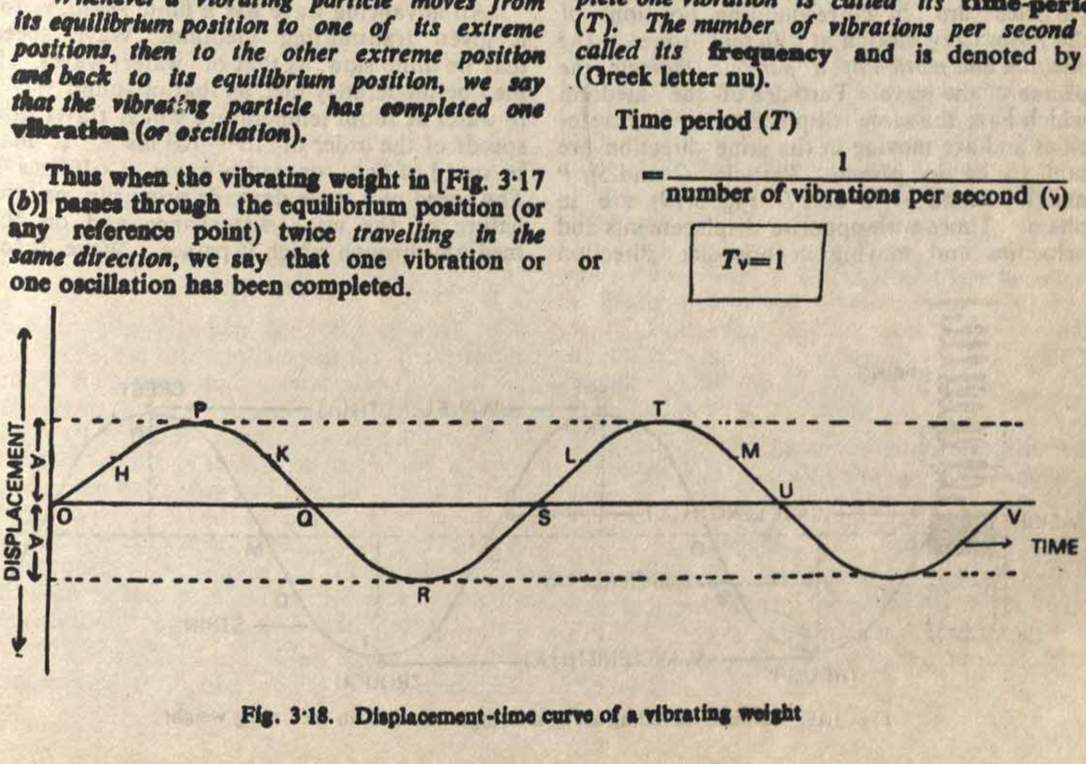


Fig. 3·18. Displacement-time curve of a vibrating weight or $\boxed{\nu=\frac{1}{T}}$ and $\boxed{T=\frac{1}{\nu}}$

This is a very important relation. Time period (T) is measured in seconds. The S.I. unit of frequency (ν) is the *hertz* (*Hz*), One hertz is equivalent to the expression "one cycle per second or one vibration per second". For example, a wave generated at 60 cycles per second has a frequency of 60 Hz which is expressed as

ν=60 cycles per second=60 Hz=60/s

Suppose we attach the left end of a long string to a weight suspended by a spring (Fig. 3.19). Assume that the weight can move up and down without friction. As the weight moves up and down, a periodic transverse wave travels to the right along the length of the string (Fig. 3.19). If we consider any part of the string, it oscillates up and down while the wave travels to the right, in the form of crests and troughs which replace one another. As a periodic wave travels through a medium (string), the particles of the medium (string) vibrate about their equilibrium positions in identical fashion. However, the particles are in corresponding positions of their vibratory motion at different times. *The position and motion of a particle indicate the* **phase** of the wave. Particles of the medium which have the same displacements and velocities and are moving in the same direction are said to be **in phase**. Particles O and S; P and T; R and N; B and D (Fig. 3·19) are in phase. Those with opposite displacements and velocities and moving in opposite direction (particles O and Q; P and R) are **in opposite phase** or **out of phase** or **180° out of phase.**

The distance between two consecutive crests or two consecutive troughs along a wave is defined as the **wavelength** and is usually denoted by the Greek letter λ called *lambda*. In Fig. (3.19), the distance RN or PT gives the wave length. It is also defined as the distance between two consecutive vibrating particles which are in the same phase. One crest and one trough also constitute one wave length. *It is also defined as the distance travelled by the disturbance* (*wave motion*) *in the time in which the particle of the medium completes one vibration.*

From Fig. (3.19) it is clear that the points separated by distances λ, 2λ, 3λ, ... are all in phase whereas the points separated by distances $\frac{\lambda}{2}$, $\frac{3\lambda}{2}$, $\frac{5\lambda}{2}$, ... are all out of phase.

The amplitude (A) of the wave is the same as the amplitude of the oscillating source [*i.e.*, oscillating weight in Fig. (3.19)]. As the wave moves forward, each point oscillates with the frequency of the source.

An advancing wave has a finite *speed*, v, for a given transmitting medium. Wave speed may be quite slow, as that of water waves. It may be moderately fast, as that of sound waves in water at room temperature which travel with speeds of the order of 10^2-10^3 ms^{-1}. It may be speed of light or radio-waves 3×10^8 ms^{-1}. The speed of a wave depends primarily on the nature of the wave disturbance and on the medium through which it passes. Wave speed

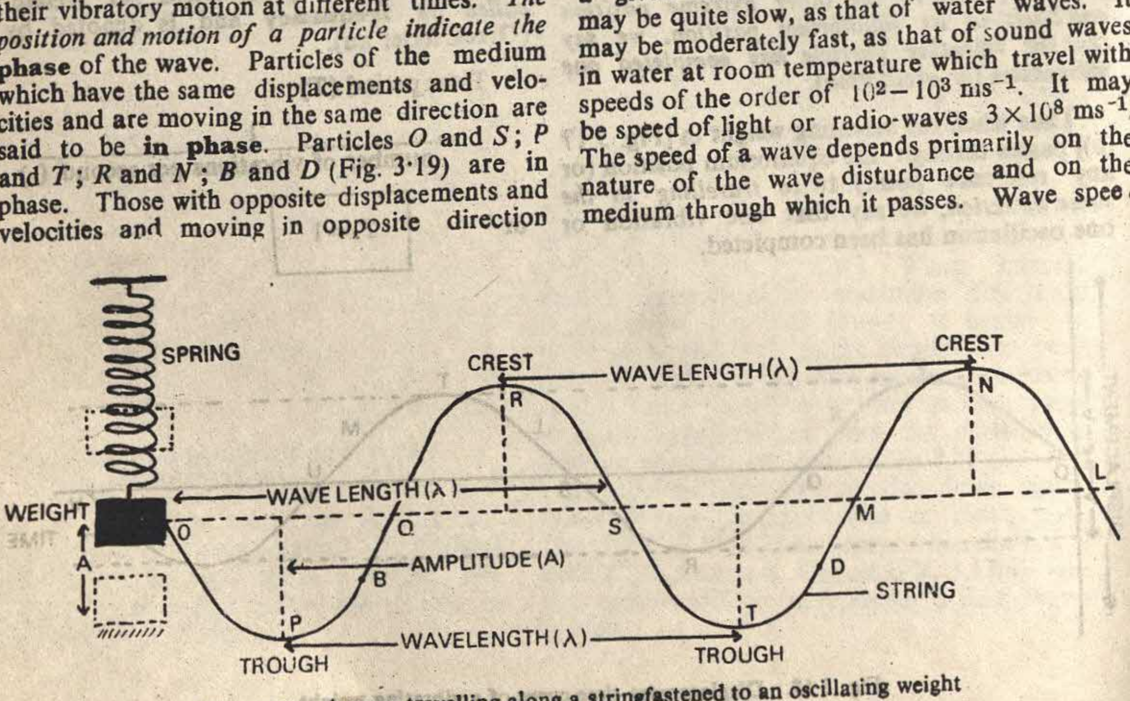


Fig. 3.19. **A wave travelling along a stringfastened to an oscillating weight**

may also depend on wave-length in certain media.

An interesting aspect of a surface wave on a liquid is that its speed of propagation depends on its wave-length. The *shorter* the wavelength, the *higher* is the wave-speed. A strong steady wind may produce surface waves of very long wavelength. In this case also, the *longer* the wavelength, the *higher* is the wave-speed. Here the wave-speed is governed by gravity which provides a restoring force and such waves are called *gravity waves*.

When the speed of a wave depends on its wave-length (or frequency) we say the transmitting medium is *dispersive*.

Since a wave-travels the distance λ in the time T for a complete vibration of the source, its speed (v) is given by the expression

$$\text{Speed} = \frac{\text{distance}}{\text{Time}}$$

$$= \frac{\text{wavelength}}{\text{time-period}}$$

or $$v = \frac{\lambda}{T}.$$

But $$\nu = \frac{1}{T} \text{ where } \nu \text{ is the frequency.}$$

$$\therefore \quad \text{Speed} = v = \frac{\lambda}{T} = \nu\lambda$$

or $$\boxed{v = \nu\lambda}$$

This shows how fast does a disturbance in a medium travel. This important equation is true for all periodic waves, whether transverse or longitudinal, no matter what the medium is.

As we have shown, the speed of any periodic wave in a medium is equal to the product of its frequency and wave-length. Note that the speed of the wave and the speed with which any part of the medium oscillates are not at all related. For one thing the speed of a wave of a given frequency in a medium is constant, whereas the speed of any one part of the medium is constantly changing as it oscillates. The speed is maximum for that part of the medium which is close to its mean position and zero at the extremes of oscillations.

In all forms of travelling waves, energy is transmitted from one point to another. The rate of transfer of energy or the power transmitted by a wave is proportional to the square of the wave amplitude and the square of the wave frequency.

To discuss other properties of waves we will choose examples where the property is most easily visualized. Hence sometimes we will consider propagation of waves in a string and at other times on water surface.

3.8. THE SUPERPOSITION OF WAVES

We have described the passage of a single pulse and a continuous wave through a medium. What happens when waves meet ? Is their motion changed as it is when solid objects collide ? It is possible for two or more wave disturbances to move through a medium at the same time. Sound waves from all the musical instruments of an orchestra move simultaneously through the air to our ears. Electromagnetic waves from many different radio and television stations travel simultaneously through regions of space to our receiving antennas. Nevertheless, we can listen to the sound of a particular musical instrument, or select a particular radio or television station. These facts suggest that each wave system proceeds independently along its pathway as if the other wave systems were not present.

Let us consider the effects of two periodic transverse waves travelling along a taut string in the *same direction*. The displacements they produce *at a particular instant* are shown in Fig. (3.20). These two waves have different amplitudes and frequencies. The displacements y_1 produced by one wave are represented by the solid curve. The displacements y_2 produced by the other wave are represented by the dashed curve. The resultant displacements y all along the string at this instant are represented by the thick solid curve. The resultant displacements are determined by adding (algebraically) the displacements y_1 and y_2 for every point along the string.

In effect, the displacement of any particle of the medium by one wave at any instant is superimposed on the displacement of that particle by the other wave at that instant. The action of each wave on a particle is independent of the action of the other, and the particle displacement is the resultant of both wave actions. This phenomenon is known as *superposition*. The two waves are said to *superpose*.

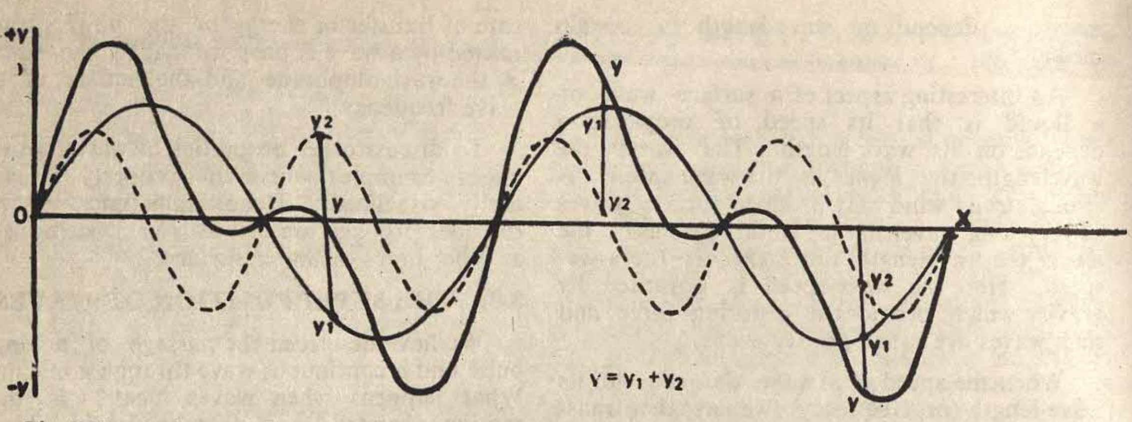


Fig. 3.20. An instantaneous view of the superposition of two periodic transverse waves of different amplitude and frequency. The component waves y_1 and y_2 are shown in black ; the resultant wave Y is thick.

The superposition principal. *When two or more sets of waves pass through and cross one another in the same medium they behave as if the other wave were not present, that is, the effects produced by one are totally independent of the effects due to the other. The resultant displacement, at any instant, of a particle depends upon the phase difference between the waves and is the vector sum of the displacements it would have at the same instant due to each separate set.*

If $y_1, y_2, y_3, \ldots$ are the displacement vectors due to the waves 1, 2, 3, ... acting separately, then, according to the principle of superposition, the *resultant displacement* (y) caused, when all the waves act together, is given by the vector sum

$$y = y_1 + y_2 + y_3 + \ldots\ldots$$

For simplicity, we shall deal only with cases where two waves superpose. Then

$$\boxed{y = y_1 + y_2}$$

The principle of superposition can be used to explain many wave effects. This principle holds for light and all other electromagnetic waves as well as for sound waves and waves on a string or on a liquid surface, provided the displacements are small. For example, it does not hold for shock waves produced by violent explosions.

3.9. INTERFERENCE

With a single source of disturbance, the distribution of energy in the surrounding medium is *uniform* but when there are two adjacent ources giving out continuous waves of the same wavelength and amplitude and having the same phase or a constant difference in phase, the distribution of energy is no longer uniform. At some points where the crest (or condensation) of one wave falls upon the trough (or rarefaction) of the other and *vice versa*, the resultant amplitude is reduced to zero and the energy is minimum. While at other points where the crest (or condensation) of one wave falls upon the crest (or condensation) of the other or trough (or rarefaction) of one falls upon the trough (or rarefaction) of the other, the resultant amplitude is increased and the energy becomes maximum. *This modification in the distribution of energy obtained by the superposition of two or more waves travelling simultaneously in the same medium is called* **interference.**

The general term *interference* is used to describe the *effects* produced by two or more waves which superpose while passing through a given region. Special consideration is given to *waves of the same frequency,* particularly in the case of sound and light. Interference phenomena are exclusively associated with waves.

Let us consider two waves of the same frequency transversing the same medium simultaneously. *Each particle* of the medium is *affected by both waves.* Suppose the displacement of a particular particle caused by one wave at any instant is in the same direction as that caused by the other wave. Then the total displacement of *that particle at that instant* is the *sum* of the separate displacements (superposition principle). The resultant displacement is *greater* than either wave would have caused separately. This effect is called *constructive interference.*

On the other hand, if the displacement effects of the two waves on the particle are in opposite directions, they tend to cancel one another. The resultant displacement of that particle at that instant is the *difference* of the two separate displacements and is in the direction of the larger (superposition principle). The resultant displacement of the particle is *less* than one of the waves would have caused separately. This effect is called *destructive interference.* If two such opposite displacement effects are *equal* in magnitude, the resultant displacement is zero. The destructive interference is complete. The particle is not displaced at all, but is in its equilibrium position at that instant.

Notice that we have been considering the effect of two waves on the position of just *one particle* of the medium *at one particular instant.* We shall continue to fix our attention on one instant in time, as we consider the displacements of many *different* particles of the medium in which the two waves are propagating. We find that the interference effects on different particles are different. There is constructive interference at some locations and destructive interference at others.

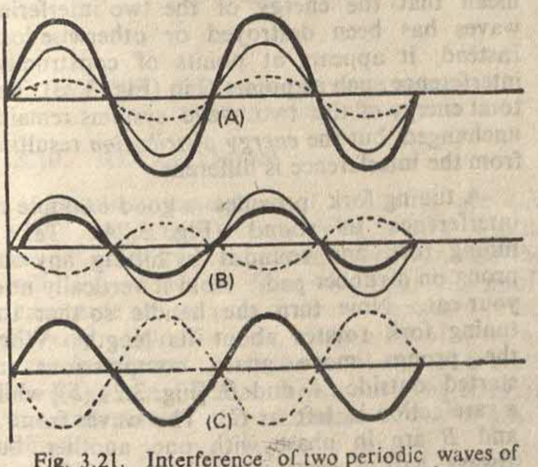


Fig. 3.21. Interference of two periodic waves of the same frequency and travelling in the same direction. The component waves are in continuous and dashed curves, the resultant wave is in thick curve (A) and (B) and thin straight line in (C); (A) Constructive interference. (B) Destructive interference. (C) Complete destructive interference.

In Fig. 3.21 (A) two periodic waves with the same frequency and in phase are travelling in the same direction. They interfere constructively. The resultant periodic wave (shown by thick curve) has the same frequency as the component waves but has an amplitude equal to the sum of the component amplitudes.

In Fig. 3.21 (B) the two periodic waves have the same frequency but are opposite in phase (180° out of phase). The displacements of the waves are opposite in sign and they interfere destructively. The amplitudes of the two waves are equal to Fig. 3.21 (C) and the destructive interference is complete.

The arrangement of interference effects (called an *interference pattern*) depends on the relative characteristics of interfering waves. Figure 3.22 is a photograph of an interference pattern produced in a ripple tank by two identical circular waves emanating from two points. The two waves are in phase at their sources. That is, the two probes which generate the waves by their vibrations are moving up and down together.

A diagram of this interference pattern is shown in Fig. 3 23 Points *A* and *B* are the sources of two periodic circular waves of the same frequency and amplitude. The sources are acting in phase. Solid circular lines represent wave troughs.

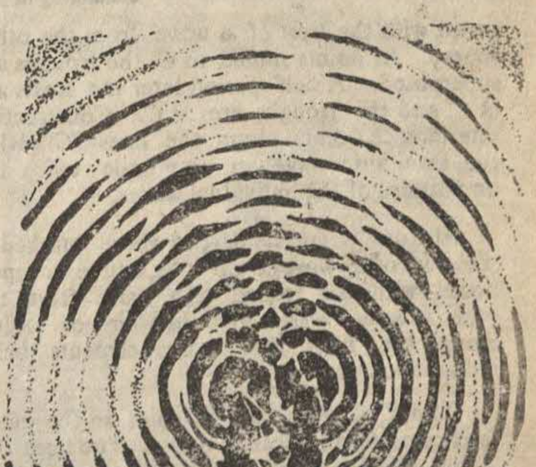


Fig. 3.22 A photograph of the interference pattern of waves from two point sources. Locate the nodal and antinodal lines.

At each point similar to those marked *C* the crest of a wave from one source is super-

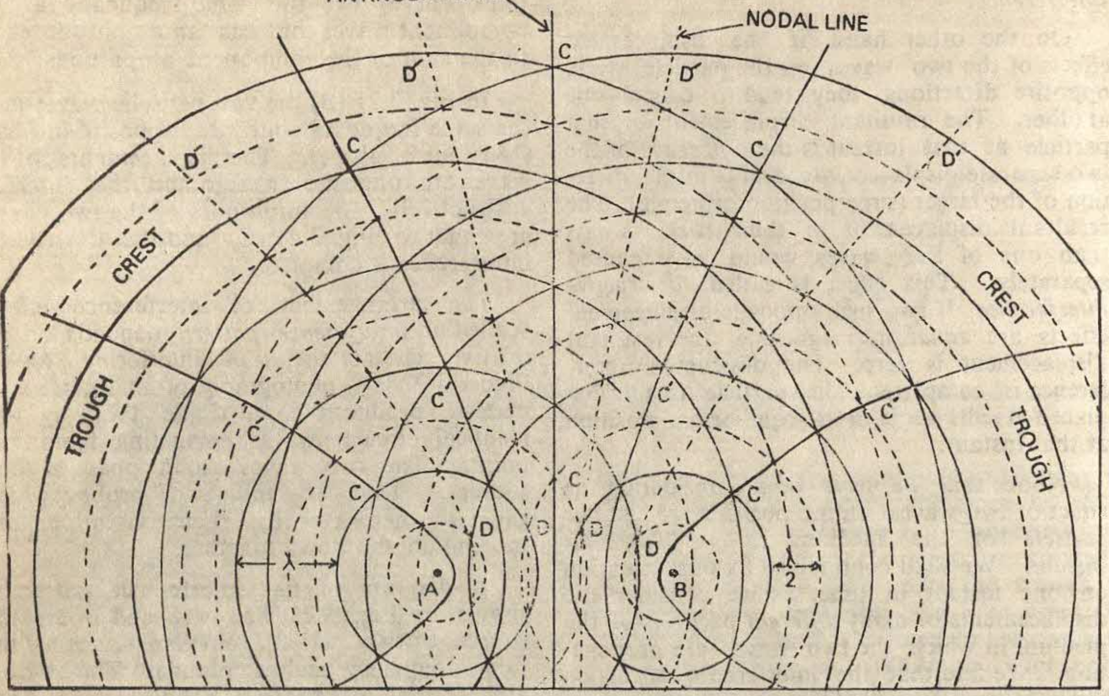


Fig. 3.23. A diagram of the interference pattern of two periodic circular waves of the same frequency emanating in phase from points A and B.

posed with the crest of a wave from the other source. At points similar to C' the troughs are superposed. A half period later the crests are at C' and the troughs are at C. Constructive interference occurs along the lines CC' giving the resultant wave an amplitude twice the amplitudes of the individual waves.

At each point similar to those marked D the crest of a wave from one source is superposed with the trough of a wave from the other source. Destructive interference occurs along the lines DD', displacements being reduced to zero.

Points of zero displacement in the interference pattern are called *nodes.* The lines DD' along which they occur are *nodal lines.* Similarly, points of maximum displacement are called *antinodes* (or loops) and the lines CC' along which they occur are *antinodal lines.* Observe these nodal and antinodal regions in the photograph of the interference pattern shown in Fig. 3.22.

At any nodal point where the destructive interference is complete, there is no motion of of the medium and no energy. This does not mean that the energy of the two interfering waves has been destroyed or otherwise lost. Instead, it appears at points of constructive interference such as points C in (Fig. 3.23). The total energy of the two wave systems remains unchanged, but the *energy distribution* resulting from the interference is different.

A tuning fork provides a good example of interference in sound (Fig. 3.24). Take a tuning fork and sound it by hitting any one prong on a rubber pad. Hold it vertically near your ear. Now turn the handle so that the tuning fork rotates about its length When the prongs move apart, compressions are started outside A and B [Fig. 3.24 (*b*)] while a rarefaction is left at C. The waves from A and B are in phase with one another but always half a cycle out of phase with those from C. Hence, the four dotted lines are the loci of points at which waves from C and those from A or B arrive exactly out of phase —compression superposed on rarefaction— and so counteract one another (destructive interference). When one rotates a vibrating tuning fork close to the ear, four alterations of loud and feeble sound are heard during one revolution.

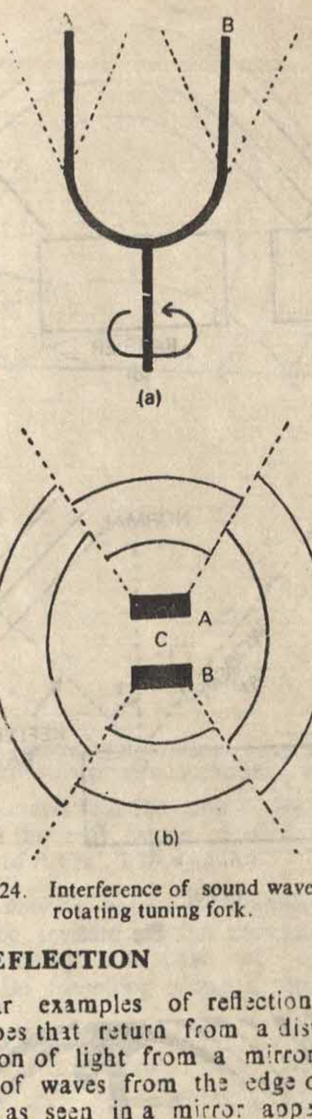


Fig. 3.24. Interference of sound waves by a rotating tuning fork.

3.10. REFLECTION

Familiar examples of reflection are the sound echoes that return from a distant wall, the reflection of light from a mirror, and the reflection of waves from the edge of a pool. Our image as seen in a mirror appears to be reversed, right for left. The crest of a water wave is reflected from the pool side as a crest travelling in a different direction. The echo of a sound retains the character of the original sound.

About the only inference we can draw from these casual observations is that *a wave is turned back* or **reflected,** *when it encounters a barrier that is the boundary of the medium in which the wave is travelling. This property of the bouncing of the waves is called* **reflection**.

Suppose we generate straight waves in the ripple tank with a straight barrier placed across the tray parallel to the advancing crests. (If we dip a ruler or any straight edge half-way in water and push it quickly back and forth, we will produce a wave in which both crests and troughs lie along straight lines. These waves are called *plane waves* or *straight waves.* If we draw lines perpendicular to the crests of the waves, then these lines are called **rays**. They are very helpful in describing the behaviour of waves). When the straight wave reaches the barrier, it is reflected back in the direction from which it came. No disturbance appears in the water behind the barrier. The paths of the incident pulse (approaching the barrier) and the reflected pulse lie perpendicular to the surface of the barrier.

The angle formed by the path of incidence (*i.e.* incident ray) and the perpendicular (normal) to the reflecting surface at the point of incidence is called *the angle of incidence, i.* The angle formed by the path of reflection (*i.e.* reflected ray) and the normal is *the angle of reflection, r.* In this instance, both the angle of incidence and the angle of reflection are 0° and $i=r$. Certainly i and r equal 0° only when the incident wave approaches the barrier along a line perpendicular to it. We may then ask whether the equality between i and r is coincidental in this situation, or is characteristic of reflection in general. To investigate the relationship of i and r further, we need to change the position of the barrier so that it is no longer parallel to the straight waves and then send more straight waves against it. A photograph of a periodic straight wave reflect-

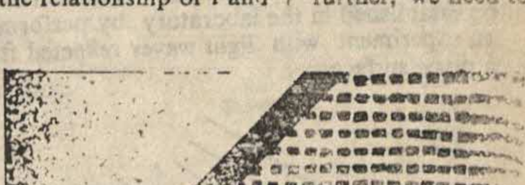


Fig 3.25 Reflection of a periodic straight wave from a diagonal barrier. The left portion of each wave crest has already been reflected toward the right.

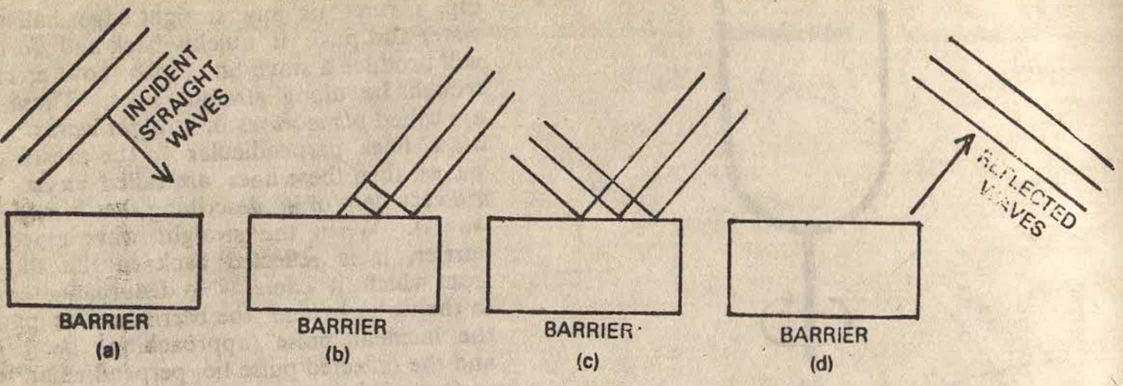


Fig. 3.26

ed from a diagonally placed barrier is shown in Fig. 3.25.

In the sketches in Fig. 3.26 are shown the various stages of incident and reflected crests. Let us draw rays for cases (*a*) and (*d*) of Fig. (3.26). These are redrawn as Fig. (3.27) and Fig. (3.28). Let the incident ray meet the reflecting surface at 0. Draw a normal to the surface at 0. It has been experimentally found that the angle between the incident ray and the normal *i.e.*, angle of incidence *i* is equal to the angle of reflection, *r i.e.* the angle between the reflected ray and the normal. This can easily be established in the laboratory by performing an experiment with light waves reflected from a plane surface.

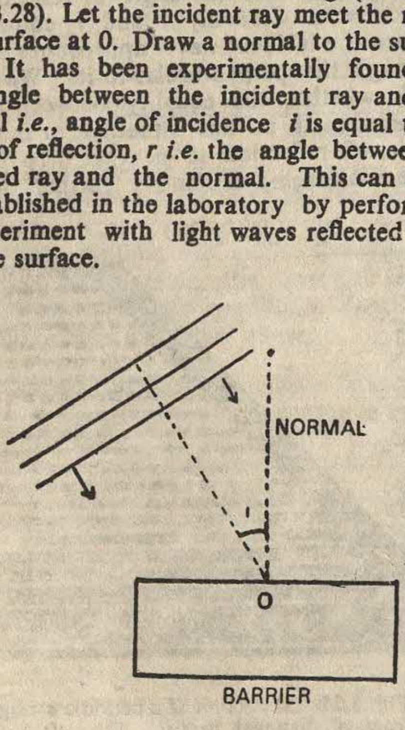


Fig. 3.27

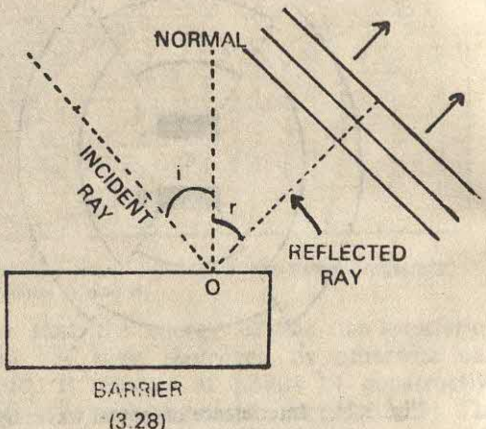


Fig. 3.28

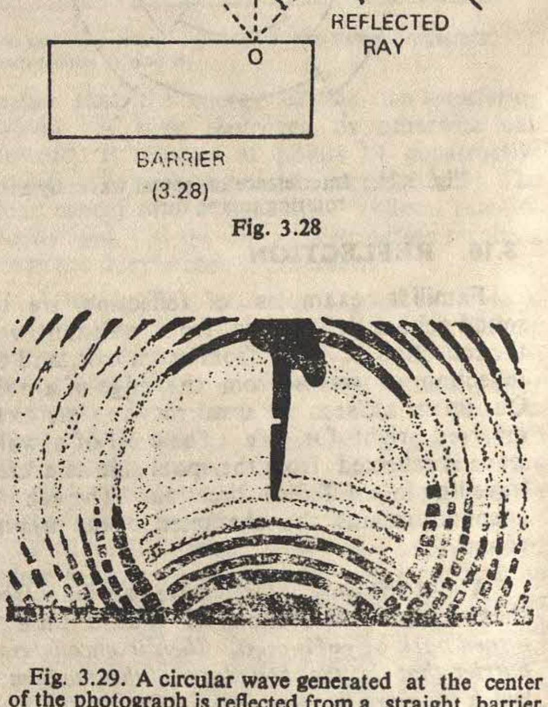


Fig. 3.29. A circular wave generated at the center of the photograph is reflected from a straight barrier

The reflection of a circular wave from a straight barrier is shown in Fig (3.29). Each segment of the expanding circular wave reflected from the barrier surface rebounds according to the *law of reflection i.e.* $i=r$. Observe that the reflected portions of the wave crests are arcs of circles. The apparent centre (I) of these

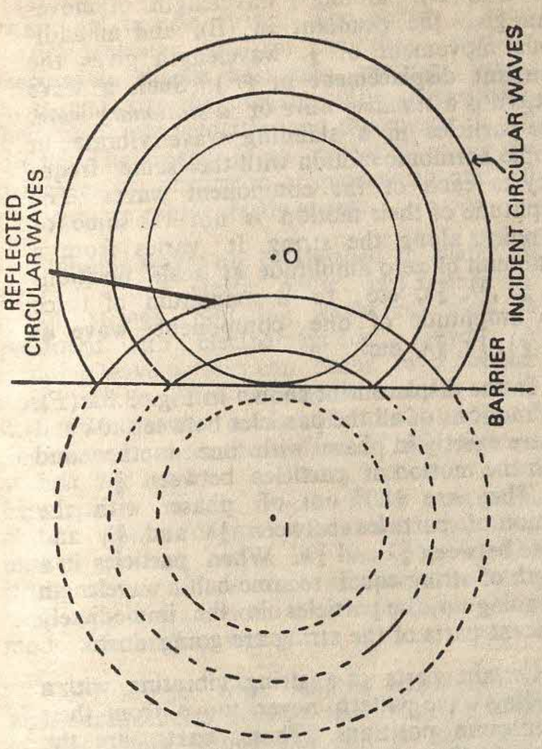


Fig. 3.30. O→centre of disturbance I→apparent centre of reflected disturbance *i.e.* the image of O.

reflected wave crests is as far behind the reflecting surface as the real centre of disturbance (0) is in front of it Fig. 3.30.

Reflection may be partial or complete, depending on the severity of the change at the reflecting boundary. Suppose we send a transverse pulse travelling along a stretched string the far end of which is free (Fig 3.31). After arriving at the free end of the string, the pulse is reflected as shown in Fig (3.31). observe that it has not been inverted. Displacement of the particles of the string is in the same direction as that of the incident pulse. ***Reflection at the free-end termination of a medium occurs without a change in phase.***

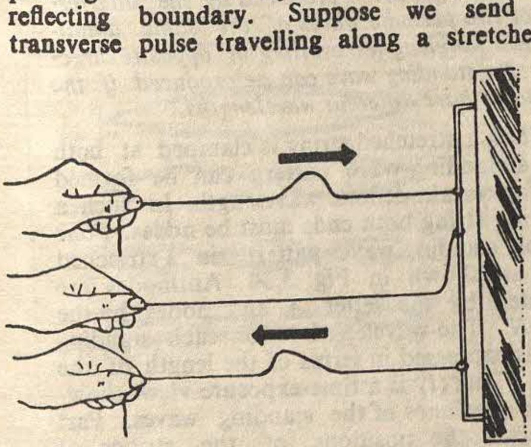


Fig. 3.31. Reflection of a pulse at the "free" end of a taut string. The string is shown terminated in a frictionless ring which allows the end segment unrestrained displacement in the plane of the pulse.

Now suppose we clamp the far end of a string in a fixed position and send a transverse pulse toward this termination (Fig 3.32.) When the pulse arrives at the fixed end, it applies an upward force to the clamp. An equal and opposite reaction force is applied to the string generating a reflected pulse which is inverted with respect to the incident pulse. ***Reflection at the fixed termination of a medium occurs with a phase shift of 180°.*** In general we may conclude that a *boundary which restrains the displacement of the particles of a meduim reflects waves inverted in phase.*

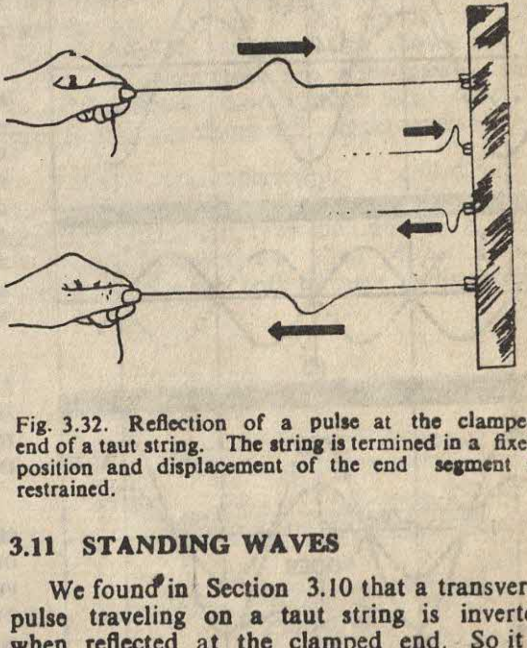


Fig. 3.32. Reflection of a pulse at the clamped end of a taut string. The string is termined in a fixed position and displacement of the end segment is restrained.

3.11 STANDING WAVES

We found in Section 3.10 that a transverse pulse traveling on a taut string is inverted when reflected at the clamped end. So it is with a train of transverse waves. If no energy is lost in reflection at the fixed end, a continuous wave will be reflected back upon itself giving two wave trains of the same wavelength, frequency, and amplitude but travelling in opposite directions.

Portions of two such wave trains are shown at a certain instant in time in (A) and (B) of Fig. 3.33. If their displacements are added at

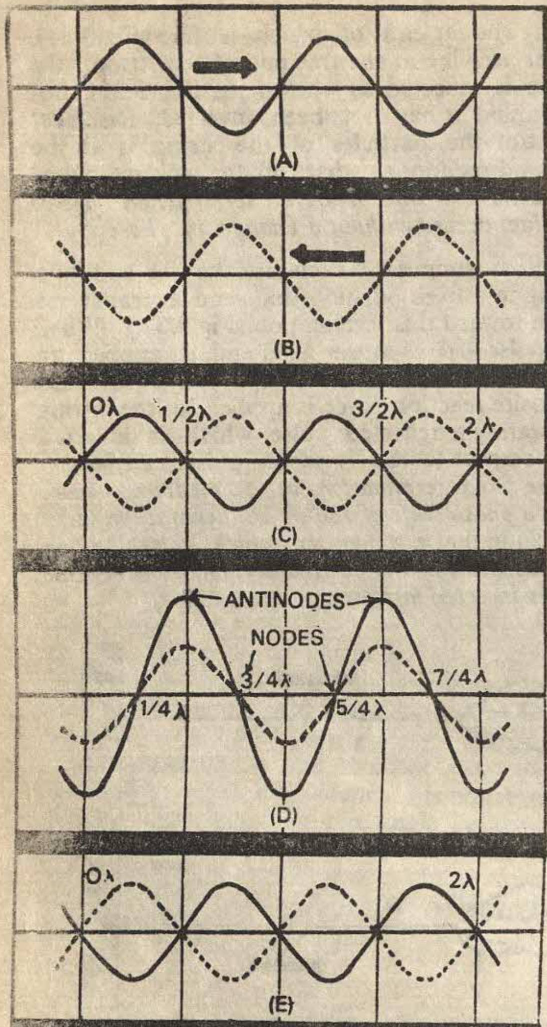


Fig. 3.33. **Standing wave** produced by the interference of two periodic waves of the same frequency and amplitude travelling in opposite directions.

at this instant, as in (C), the resultant displacement is zero. When the wave patterns have moved $\frac{1}{4}$ wavelength, each in its own direction of travel, superposition gives the resultant shown in (D). Another $\frac{1}{4}$ wavelength of movement gives the resultant in (E), and an additional movement of $\frac{1}{4}$ wavelength gives the resultant displacement in (*F*). Such a wave pattern is a *standing wave* or *a stationary wave*. The particles in a standing wave vibrate in simple harmonic motion with the same frequency as each of the component waves. The amplitude of their motion is not the same for all points along the string. It varies from a minimum of zero amplitude at scale positions $\frac{1}{4}\lambda$, $\frac{3}{4}\lambda$, $\frac{5}{4}\lambda$, $\frac{7}{4}\lambda$, etc, to a maximum of twice the amplitude of one component wave at 0λ, $\frac{1}{2}\lambda$, 1λ, $\frac{3}{2}\lambda$, etc.

In the displacement shown in Fig. 3.33 (*F*), the motions of all the particles between 0λ and $\frac{1}{4}\lambda$ are exectly in phase with one another and with the motion of particles between $\frac{3}{4}\lambda$ and $\frac{5}{4}\lambda$. They are 180° out of phase with the motion of particles between $\frac{1}{4}\lambda$ and $\frac{3}{4}\lambda$ and those between $\frac{5}{4}\lambda$ and $\frac{7}{4}\lambda$. When particles in a length of string equal to one-half wavelength are going up, the particles in the immediately adjacent parts of the string are going down.

Certain parts of a string vibrating with a standing wave pattern never move from their equilibrium positions. These parts are the *nodes*. Halfway between the nodes, where the amplitude of vibration is maximum, are the *antinodes*. The wavelength of the component periodic transverse waves which produce the standing wave is *twice* the distance between adjacent nodes or *antinodes* in a standing wave.

A standing wave is produced by the interference of two periodic waves of the same amplitude and wavelength travelling in opposite directions. No standing wave can be produced if the two waves have different wavelengths.

When a stretched string is clamped at both ends, a standing wave pattern can be formed only for certain definite wavelength. In such a vibrating string both ends must be nodes. Four possible standing wave patterns in a stretched string are shown in Fig. 3.34 Antinodes are indicated by the letter *A* and nodes by the letter *N*. The wavelength λ for each standing wave is expressed in terms of the length of the string, *l* Part (*i*) is a time-exposure view showing the envelopes of the standing waves. Part (*ii*) shows the positions of the strings at different instants of time.

In a standing waves, particles of the string at the nodes are continuously at rest. Energy is transported along the string, but remains "standing" in the string. The energy of each particle remains constant as that particle executes its simple harmonic motion. When the string is straight (undistorted), particles have their maximum velocities and the energy is all kinetic. The energy is all potential when the string has its maximum displacement and all particles are momentarily at rest.

Standing waves are established in water in air, or in other elastic bodies just as they are in taut strings. Standing waves can also be produced with electromagnetic waves. A standing wave pattern can occur in a circular ripple tank in which a periodic circular wave is generated at the center of the tank. Nodal rings appear where the surface of the water is at rest. The surface oscillates up and down between the nodal rings. Many vibrating objects vibrate normally in a way that establishes standing waves in the object. The strings or the air columns of musical instruments (*e.g.* guitar, violin etc.) establish various modes of standing waves.

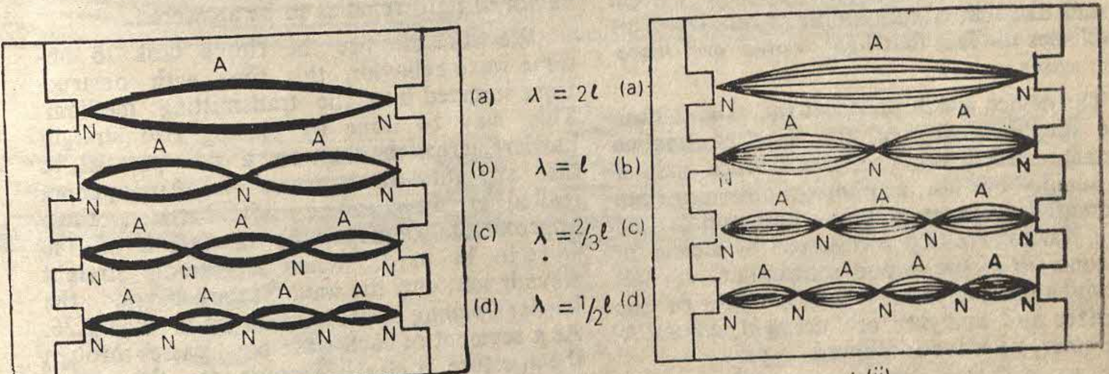
Since shorter wave lengths correspond to higher frequencies $(\nu = \nu\lambda)$ the standing waves of only certain frequencies can be set up. If ν_0 is the lowest possible frequency (*fundamental frequency*) of the standing wave, the other possible standing waves that can be set up will have frequencies $2\nu_0$, $3\nu_0$,……These higher frequencies are called *overtones* or *harmonic* of the fundamental frequency ν_0.

3.12 POLARIZATION IN WAVES

The phenomenon according to which the wave oscillations are restricted to a particular plane is called polarization. A wave having oscillations in all possibles directions is said to be *unpolarised.* When all the oscillations of a wave get confined along one direction, the wave is called *plane polarized e.g.*, electromagnetic waves from radio, television and radar aerials are plane polarized.

Consider a string with its one end *A* held in the hand and the other tied to a hook *B* in a wall after passing through two rectangular slits made in the screens S_1 and S_2 (Fig. 3.35). Let the end *A* be jerked in all sorts of directions perpendicular to the length of the string so as to produce *transverse waves* in it. The first slit S_1 will permit only such vibrations to pass through it which are parallel to it and obstruct all other vibrations. If the second slit S_2 is held paralled to the slit S_1 [Fig 3.35 (*a*)] the vibrations passing through S_1 will also pass through S_2. But if the slit S_2 is held perpendicular to the slit S_1 as shown in Fig. 3.35 (*b*) the vibrations passing through S_1 will be refused transmission through S_2 so that the part S_2 *B* of the string will remain undisturbed.

If the string is replaced by a coiled spring and given longitudinal vibrations of compression and rarefaction, they shall not be blocked by the slits irrespective of their direction but would pass through both of them undisturbed.



(i)

(ii)

Fig. 3.34. Standing waves in stretched string

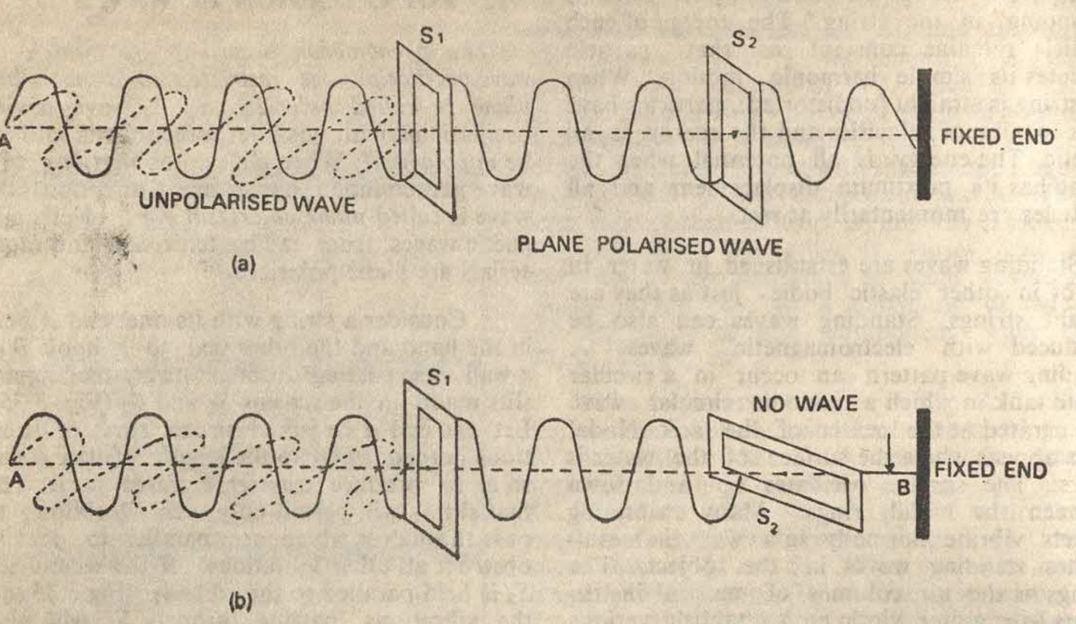


Fig. 3.35

Thus these are transverse vibrations which are obstructed by the slit (except those which are parallel to its length) and not longitudinal vibrations. Thus such an experiment on polarization of waves clearly distinguishes a transverse wave from a longitudinal wave. In other words, polarization of a wave is a property which distinguished the behaviour of a transverse wave from that of a longitudinal wave

We come across an exactly similar situation when light is made to pass through certain crystals like that of tourmaline or quartz. This establishes the fact that *light waves are transverve wases.*

The device which produces the polarization (like the first slit, or the first tourmaline crystal) is called the *polarizer*. Since neither the unaided eye nor a photographic film can differentiate between polarized and unpolarized wave, the polarization is observed by means of a second slit S_2 (or second tourmaline crystal) known as the *analyzer*. When the axes of the polarizer and analyzer are *at right angles to each other*, no wave is allowed to pass.

3.13. DIFFRACTION

Sounds can be heard even though they may originate around the corner of a building. The source of the sound disturbance cannot be seen around the corner, however. Rectilinear propagation appears to hold in this situation for light but not for sound. The building is an obstruction which prevents the straight-line transmission of light from the source of the sound disturbance to the observer.

Perhaps, where sound waves are concerned, the corner of the building creates a discontinuity in the transmitting medium which causes the waves to *spread*. Even if we find support for this idea, the question of the different behavior of light remains to be answered.

We will again use the ripple tank to observe wave behavior, this time with obstructions inserted into the transmitting medium. This may be done by placing two straight barriers across the tray on a line parallel to the straight wave generator. An opening (called an *aperture*) is left between them approximately equal to the wavelength of the wave to be used. When a periodic straight wave is sent out, the wave pattern beyond the barrier opening appears as shown in Fig. 3.36. As a segment of each wave crest passes through the aperture, it clearly spreads into the region beyond the barriers. This spreading of a wave disturbance beyond the edge of a barrier is called **diffraction.** The phenomenon of diffraction is shared by all types of waves.

Sound waves spread around the edges of doorways in the same way water waves spread

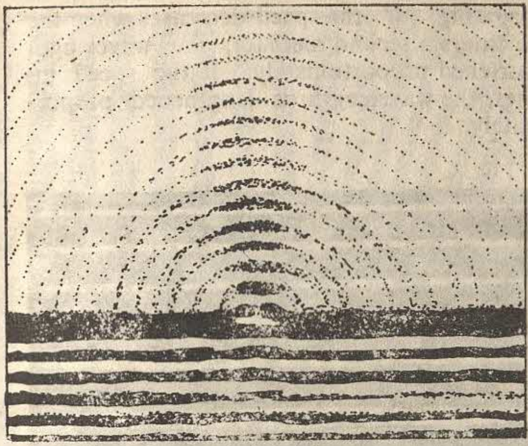


Fig. 3·36. The diffraction of a periodic straight wave as it passes through a small aperture.

around the edges of obstructions. Audible sounds have wavelengths in air ranging from a few centimeters to several meters. The doorway of a room or building has dimensions within this range. This suggests, but does not prove, that a discontinuity such as an aperture in the path of an advancing wave will diffract the wave if its dimensions are comparable to the wavelength of the oncoming wave.

We produced the diffraction pattern in the ripple tank with a barrier aperture approximately the same width as the wavelength of the surface wave used. Suppose we shorten the wavelength by increasing the frequency of the wave generator stepwise and observe a series of patterns with waves of decreasing wavelengths, the spreading of the wave at the edges of the aperture diminishes as the wavelength of the wave sent against them is shortened. When the wavelength is a small fraction of the width of the opening between the barriers, the wave segments passing through show little tendency

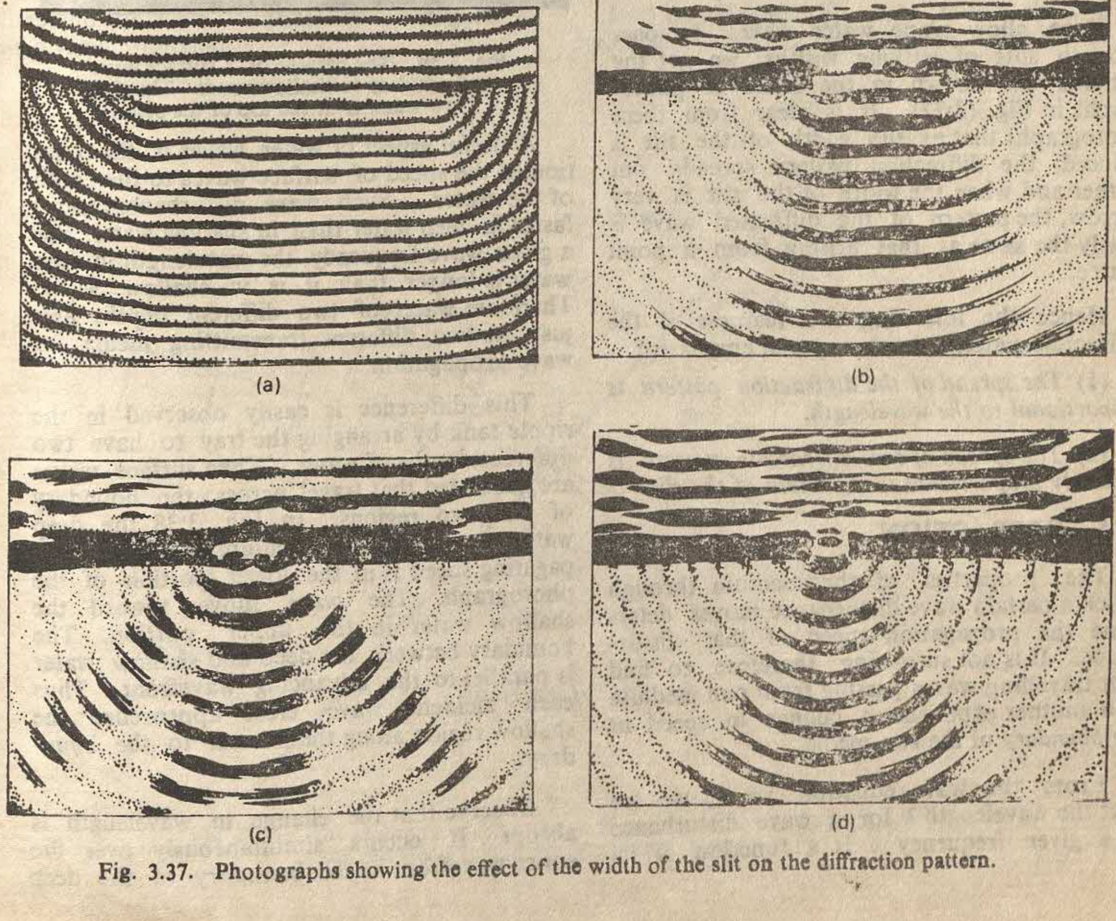


Fig. 3.37. Photographs showing the effect of the width of the slit on the diffraction pattern.

to spread into the shadow regions beyond the barriers. These observations suggest that if the wavelength is very much smaller than the width of the aperture there will be no diffraction. The part of the straight wave that passes through the opening will continue in straight-line propagation.

How are these observations related to the fact that light is not diffracted at the edges of a doorway as is sound. The speed of light in air is high, being of the order of 3×10^8 m/s. We have not yet dealt with light frequencies, but if they were extremely high, light wavelengths (v/ν) would be very short. Then it would not be surprising to find that light is diffracted only by apertures having very small dimensions.

Indeed, the wavelength of visible light ranges from approximately $7{\cdot}5\times10^{-7}$ m down to about 4×10^{-7} m. This range of wavelengths suggests that the diffraction of light occurs in the realm of extremely small dimensions.

If we allow plane water waves to pass through slits of varying widths, we get the patterns as shown in the series of photographs in Fig. (3·37). It is clear from these photographs that as the width of the slit is reduced, the diffraction pattern spreads out farther and when the width of the slit is very narrow, the pattern of the diffracted wave is nearly the same as that arising from a point source.

Hence the following two features of the diffraction pattern deserve special emphasis :

(1) *The spread of the diffraction pattern is proportional to the wavelength.*

(2) *The spread of the diffraction pattern is inversely proportional to the width of the slit.*

3.14. REFRACTION

The properties of the medium through which a certain wave disturbance moves determine the propagation speed of that disturbance. It is not surprising, therefore, to find that travelling waves passing from one medium into another experience a change in speed *at the boundary* of the two media.

From the wave equation, $v=\nu\lambda$, we see that the wavelength λ for a wave disturbance of a given frequency ν is a function of its speed v in the medium through which it is propagating. If the speed decreases when the wave enters a second medium, the wavelength is shortened proportionately. If the speed increases, the wavelength is lengthened proportionately.

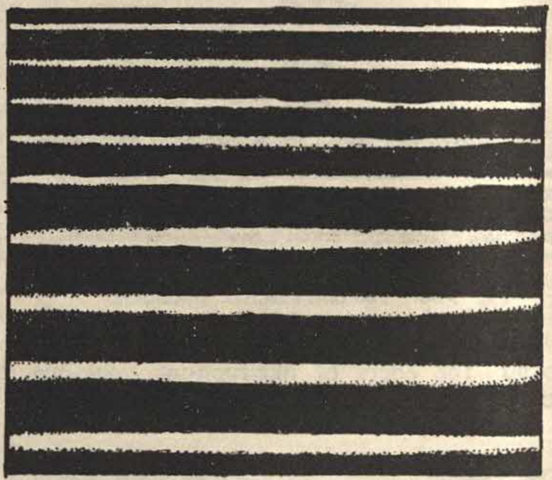


Fig. 3.38. The passage of a surface wave from deep to shallow water. The shallow water is at the top of the picture.

A useful aspect of water waves is the relation of the speed of surface waves to the depth of the water. Such wave disturbances travel faster in deep water than in shallow water. For a given wave frequency, the wavelength in deep water is longer than it is in shallow water. Therefore water of two different depths acts just like two different transmitting media for wave propagation.

This difference is easily observed in the ripple tank by arranging the tray to have two different depths of water. Then surface waves are generated that travel across the boundary of the two regions. In Fig. 3·38 the deep water representing the medium of higher propagating speed is in the lower portion of the photograph. The wave moves toward the shallow water in the upper portion. The boundary between the deep and shallow water is parallel to the advancing wavefront. Thus each incident wave crest approaches the shallow region along the normal to the boundary.

Observe that the change in wavelength is abrupt. It occurs simultaneously over the entire wavefront at the boundary of the deep

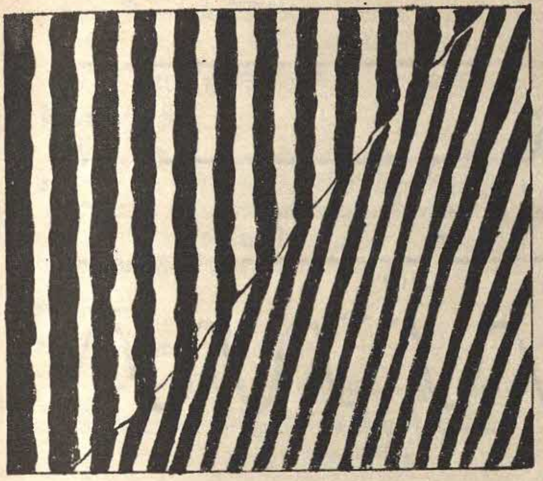


Fig. 3.39. Refraction of a surface wave at the boundary of deep and shallow water in a ripple tank.

and shallow water. All segments of the advancing wavefront change speed at the same time and the wave continues to propagate in its original direction.

Suppose we adjust the deep and shallow regions of the tray so that the boundary is no longer parallel to the advancing straight wave but cuts diagonally across its path. This arrangement is shown in Fig. 3.39. Each advancing wave crest now approaches the boundary obliquely. Adjacent segments of the wavefront pass from deep to shallow water successively rather than simultaneously. At the boundary, the direction of the wave changes ; the advancing wave has undergone *refraction*. **Refraction** is the bending of the path of a wave disturbance as it passes obliquely from one medium into another of different propagation speed.

The refraction of surface waves on water is shown by diagram in Fig. 3.40. As the wave passes into the shallow water where its speed is less and its wavelength is shorter, it is refracted *toward* the normal drawn to the deep-shallow boundary. The angle of refraction *r* is smaller than the angle of incidence *i*. (The angle *r* is the angle between the path of the refracted wave and the normal.)

Had we generated the wave in the shallow region and directed it obliquely toward the

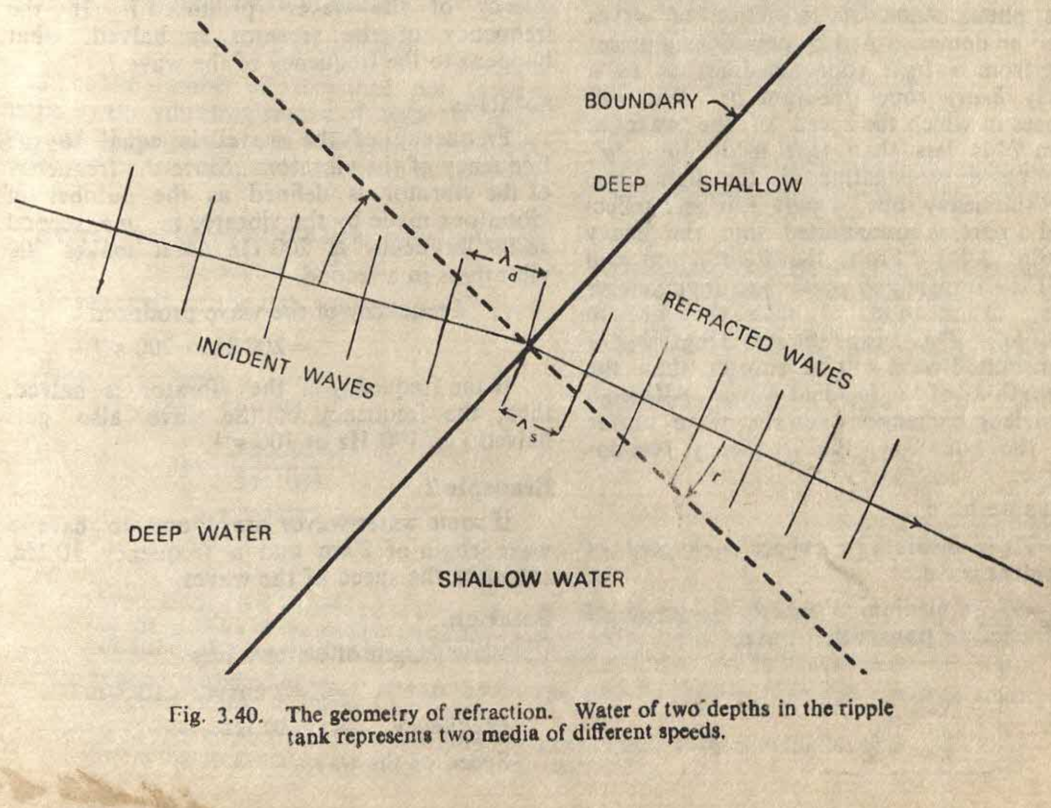


Fig. 3.40. The geometry of refraction. Water of two depths in the ripple tank represents two media of different speeds.

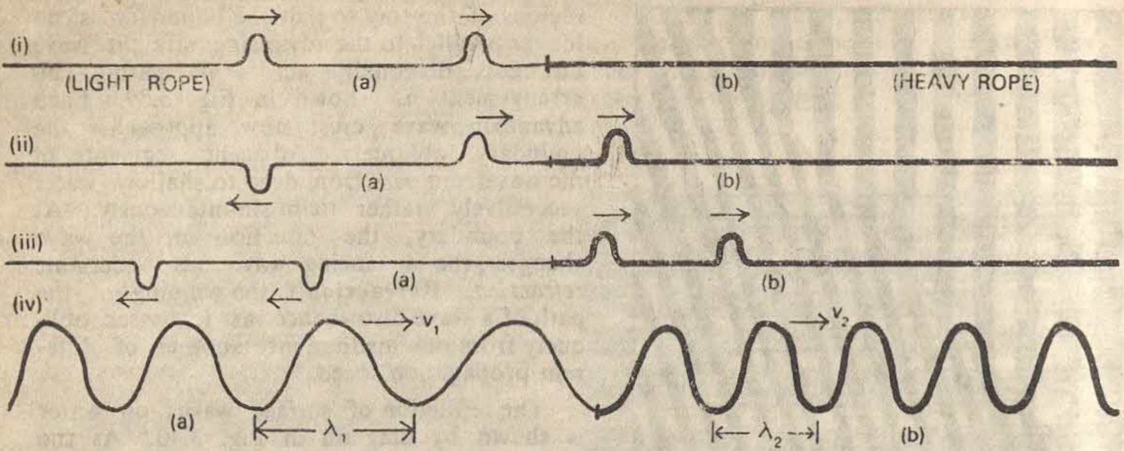


Fig. 3.41

boundary, it would have been refracted *away from* the normal on entering the deep water. Angle *r* would have been larger than *i*. The change in direction and the change in speed occur simultaneously. How are these two changes related ? We shall investigate this question quantitatively later when we study optical refraction. There the measurements we need can be made with reasonable precision.

The phenomenon of refraction of waves can also be demonstrated by considering pulses moving from a *light* rope (medium *a*) to a relatively *heavy* rope (medium *b*). We will take cases in which the speed of the wave in medium '*b*' is less than that in medium '*a*'. As a pulse propagating in the light rope reaches the heavy rope, a part of it gets reflected and a part is transmitted into the heavy rope (Fig. 3.41). From the figure, you will see that the transmitted pulses are drawn closer together in medium '*b*' than they are in medium '*a*'. This means the wavelength λ_2 of the transmitted wave will be shorter than the wavelength λ_1 of the incident wave. Although the wavelength changes when the wave moves across the boundary, the frequency remains the same.

Thus we have

$v_1 = \nu\lambda_1$ in medium '*a*' where v_1=speed of the incident wave

and $v_2 = \nu\lambda_2$ in medium '*b*' where v_2=speed of the refracted or transmitted wave.

$$\therefore \quad \boxed{\frac{v_1}{v_2} = \frac{\lambda_1}{\lambda_2}}$$

i.e. the ratio of the wavelengths in the two media is equal to the ratio of the speeds of the waves.

SOLVED EXAMPLES

Example 1

If the vibrator in a ripple tank strikes the water 200 times in a second, what is the frequency of the waves produced ? If the frequency of the vibrator is halved, what happens to the frequency of the wave ?

Solution.

Frequency of the waves is equal to the frequency of the vibrator. Since the frequency of the vibrator is defined as the number of vibrations made by the vibrator in one second so its frequency is 200 Hz as it makes 200 vibrations in a second.

$\therefore$ Frequency of the wave produced

$$= 200 \text{ Hz} = 200 \text{ s}^{-1}.$$

If the frequency of the vibrator is halved, then, the frequency of the wave also gets halved *i e.*, 100 Hz or 100 s^{-1}.

Example 2.

If some water waves are found to have a wave length of 2 cm and a frequency 10 Hz, calculate the speed of the waves.

Solution.

Wave length of water waves

$$= \lambda = 2 \text{ cm} = 2 \times 10^{-2} \text{ m}$$

Frequency $= \nu = 10$ Hz

Speed of the waves $= v = $?

Since $v=\nu\lambda$

∴ $v=10\times2\times10^{-2}$ m/s

$=\mathbf{0{\cdot}2\ m/s}$

Example 3.

Velocity of light in vacuum is 3×10^8 m/s and that in water is $2{\cdot}3\times10^8$ m/s. If the wave-length of a wave in vacuum is 6×10^{-7} m, what will be its wave-length in water ? What is the frequency of the wave ?

Solution.

In Vacuum

Velocity of light in vacuum$=v_1=3\times10^8$ m/s

Wave length of light wave in vacuum

$=\lambda_1=6\times10^{-7}$ m

Frequency of the light wave$=\nu=$?

Since $v_1=\nu\lambda_1$

∴ $3\times10^8=6\times10^{-7}\times\nu$

$$\therefore \quad \nu=\frac{3\times10^8}{6\times10^{-7}}$$

$$=\mathbf{5\times10^{14}\ s^{-1}}$$

In water.

Velocity of light wave in water

$=v_2=2{\cdot}3\times10^8$ m/s

Since the number of vibrations per second made by the vibrating source of light is independent of the medium in which it is vibrating, its frequency in vacuum is the same as that in water.

Hence, Frequency of the light wave in water

$=\nu=5\times10^{14}\ s^{-1}$

Wave length of the light wave in water

$=\lambda_1=$?

Since $v_2=\nu\lambda_2$

∴ $2{\cdot}3\times10^8=5\times10^{14}.\lambda_2$

$$\text{or} \quad \lambda_2=\frac{2{\cdot}3\times10^8}{5\times10^{14}}$$

$$=\mathbf{4{\cdot}6\times10^{-7}\ m}$$

Example 4.

If a tuning fork vibrates with a frequency of 512 Hz to produce sound waves which travel with a velocity of 330 m/s, find the wave length.

Solution.

Frequency of the tuning fork$=\nu=512$ Hz. This is also the frequency of the sound waves.

Velocity of sound waves$=v=330\ ms^{-1}$.

Wave length of sound waves$=\lambda=$?

Since $v=\nu\lambda$

$$\therefore \quad \lambda=\frac{v}{\nu}$$

$$=\frac{330}{512}$$

$$=\mathbf{0{\cdot}645\ m}$$

Example 5.

A mass at the end of a horizontal spring is stretched 0·10 m from its rest position and then released. It takes 0·75 s for the mass to move through its rest position to its extreme position in the opposite direction.

(*a*) What is the amplitude of the motion ?

(*b*) What is its period ?

(*c*) What is its frequency ?

Solution.

(*a*) Since the amplitude is the maximun displacement, so the amplitude of the motion

$=A=\mathbf{0{\cdot}10\ m}$

(*b*) Since it takes 0·75 s for the mass to make a one-way trip from one side to the, other, the time for a round trip will be $2\times0{\cdot}75=1{\cdot}5$ s. Hence time period $(T)=\mathbf{1{\cdot}5\ s}$

$$(c)\ \text{Frequency}\ (\nu)=\frac{1}{T}$$

$$=\frac{1}{1{\cdot}5}\ s^{-1}$$

$$=\mathbf{0{\cdot}67\ s^{-1}}\ \text{or}\ \mathbf{0{\cdot}67\ Hz}$$

SUMMARY

1. Wave motion is a *disturbance* in the medium due to repeated, periodic and to and fro motion of the particles of the medium about their mean position. The whole of the medium is not disturbed all at once but the motion is handed over from one particle to another.
2. Wave is a method of ***energy propagation*** through space which involves periodic variations in the medium through which the wave travels.
3. A number of phenomena characterizing waves can be demonstrated in the laboratory by water waves using a simple apparatus known as the ripple tank.

4. *Longitudinal wave*. The particle motion is *parallel* to the direction of the wave *e.g*, sound wave in air.

5. *Transverse wave*. The particle motion is *perpendicular* to the direction of the wave *e.g.*, light wave ; ripples in water.

6. *Periodic motion*. Motion which repeats itself after a fixed time interval.

7. *Time-period* (*T*). The time interval during which a physical system completes one full cycle of motion.

8. *Frequency* (ν). The number of vibrations (or complete cycles) per second

$$\boxed{\nu=\frac{1}{T}}$$

Its unit in S.I. system is *hertz* (Hz).

9. *Displacement*. The distance of a moving system from its equilibrium position at some instant of time.

10. *Amplitude* (*A*). It is the maximum value of the displacement.

11. *Wave length* (λ). The distance between any two consecutive points on a wave pattern which are in *the same phase*. It is also the distance travelled by the wave in a medium in a time during which a vibrating particle of the medium completes one full vibration.

In a transverse wave, one crest and one trough constitute one wave length while in a longitudinal wave one condensation (or compression) and one rarefaction constitutes one wave-length.

12. *Speed of a wave*. Speed of a wave = Frequency × wave-length

$$\boxed{v=\nu\lambda=\frac{\lambda}{T}}$$

13. *Crest* in a transverse wave is a point at a maximum displacement *above* its equilibrium (or mean) position.

14. *Trough* in a transverse wave is a point at the maximum displacement below its mean position.

15. *Condensation or Compression* in a longitudinal wave is a region where the particles of the medium come closer together. In this region, the density or pressure is *greater* than the normal.

16. *Rarefaction* in a longitudinal wave is a region where the particles of the medium go farther apart. In this region, the density or pressure is less than the normal.

17. *Phase* of a vibrating particle in a wave-motion is that physical quantity which determines its position and direction of vibration at some instant of time. In fact it is the stage in a cycle that a wave (or other periodic system) has reached at a particular time or at a particular place.

18. Two vibrating particles in a wave-motion are said to be *in phase* if they are lying at the same position and are ready to vibrate in the same direction. If they are lying in the same position but are ready to vibrate *in the opposite direction*, they are said to be in *opposite phase* or *out of phase* or *out of 180° phase*.

19. *Super-position principle*. Two or more waves can pass through the same region of space independently of one another. The resulting displacement of the medium is the sum of the displacements caused by the individual waves.

$$y=y_1+y_2+y_3+\ldots\ldots$$

20. *Standing* (*or Stationary*) *Wave*. A wave pattern produced by two superimposed travelling waves of the *same* frequency, amplitude and speed, moving in opposite directions in the same medium. At some positions the amplitude is zero (*nodes*) ; at other positions the amplitude is a maximum (*antinodes* or *loops*).

21. By the *interference* of two waves we mean the result of super-imposing the two waves on the same medium.

If we have two transverse waves travelling along a string in the same direction, with the same frequency and the same amplitude, the resulting motion of the string will depend upon the algebraic addition (*i.e.*, with the proper sign) of the displacements due to the two waves at every point along the string. How the displacements add will depend on the relative phases of the two waves.

In *constructive interference* at every point the displacements of the string produced by the two waves add constructively.

In *destructive interference*, the two waves are 180° out of phase The negative displacements of one wave cancel the positive displacements of the other, and the result is no motion of the string

22. *Reflection* of a wave from a fixed end causes a phase change of 180° ; reflection of a wave from a free end causes no change of phase.
When a wave coming from one medium falls on the surface of another medium, it will bounce back. This property of the bouncing of the waves is called reflection.

23 *Diffraction* is the property of waves of turning round the edges of an obstacle (or bending of waves round corners). The spread of the diffraction pattern is proportional to the wave length and inversely proportional to the width of the slit.

24. Whenever a wave travels from one medium to another, it gets its path changed and hence it experiences a change in speed at the boundary of the two media. This phenomenon is called *refraction* of waves.

$$\boxed{\frac{v_1}{v_2} = \frac{\lambda_1}{\lambda_2}}$$

25. *Polarization* is a phenomenon according to which the wave oscillations are restricted to a particular plane. When all the oscillations of a wave get confined along one direction, the wave is called *plane polarized.*

Polarization distinguishes the behaviour of transverse waves from that of longitudinal waves.

Transverse waves can be polarized whereas longitudinal waves cannot be polarized.

Light waves are transverse waves.

QUESTIONS

(A) Objective-Type Questions

1. In wave motion, a single disturbance which is not repeated is known as
   (*a*) peak
   (*b*) pulse
   (*c*) transverse wave
   (*d*) longitudinal wave.

2. A wave in which the particles of the medium vibrate at right angles to the direction in which the energy travels is known as
   (*a*) a pulse
   (*b*) electromagnetic
   (*c*) transverse
   (*d*) compressional.

3. A sound wave in air is
   (*a*) longitudinal
   (*b*) transverse
   (*c*) torsional
   (*d*) electric.

4. Pranav holds on to one end of a stretched spiral spring, Ashish to the other, Arun pinches several coils close together. This distortion is known as a

   (*i*) trough

   (*ii*) crest

   (*iii*) rarefaction

   (*iv*) compression.

5. A tuning fork vibrates in air. The number of compressions going past a given point per second is the

   (*a*) wavelength

   (*b*) time-period

   (*c*) frequency

   (*d*) amplitude

   (*e*) phase.

6. Rinku produces a certain note when she strikes a tuning fork gently. If she strikes the fork harder, the most probable change will be that the sound wave will

   (*a*) travel faster

   (*b*) have a higher frequency

   (*c*) have a greater amplitude

   (*d*) have a longer period.

7. If a stationary (standing) wave pattern is set up in a spring, certain parts of the spring never move from their equilibrium position. These parts are known as

   (*a*) nodes

   (*b*) antinodes

   (*c*) loops

   (*d*) crests.

8. At a given temperature, all sound waves in air have the same

   (*a*) frequency

   (*b*) speed

   (*c*) time period

   (*d*) intensity.

9. If the frequency of vibration of an object in air is increased, the characteristic of the resulting wave which must change is the

   (*a*) amplitude

   (*b*) speed

   (*c*) wavelength

   (*d*) intensity.

10. The speed of certain water wave is 5 m/s. If its wavelength is 2 *m*, its frequency is ....

11. When two sound waves of the same frequency are superposed on one another, the resulting phenomenon is known as

    (*a*) interference

    (*b*) resonance

    (*c*) an echo

12. A sound wave in air has a frequency of 500 Hz. Its period is................

13. If the speed of sound in air is 350 ms^{-1} and its frequency is 1000 Hz, the wavelength is.................

14. ~~One wavelength is the distance between~~.................

15. The frequency of the note produced by the simplest mode of vibration is known as...... ~~............and other notes of multiple frequencies are known as~~.................

16. Velocity of the wave × time period = ...

17. ~~Two waves having the same amplitude and frequency~~ travel in phase through the same medium and are superposed. The resulting wave will have an increased

(*i*) speed

(*ii*) frequency

(*iii*) amplitude

(*iv*) time-period.

18. In Fig. (3.42), one wavelength is the distance between point *A* and point.................

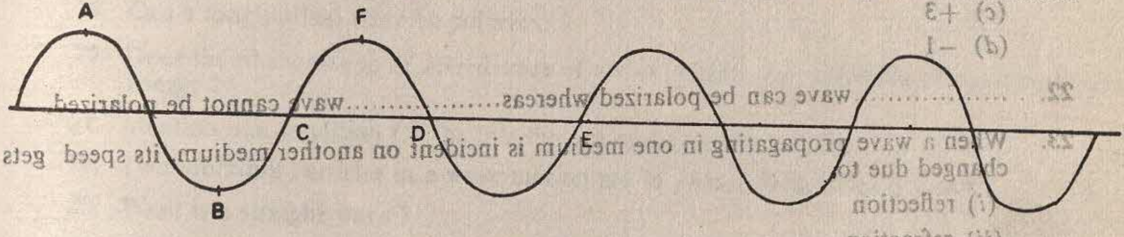


Fig. 3.42

19. In Fig. (3.43), (*a*) the wave with the greatest amplitude is ....
(*b*) the wave with the longest period is.................

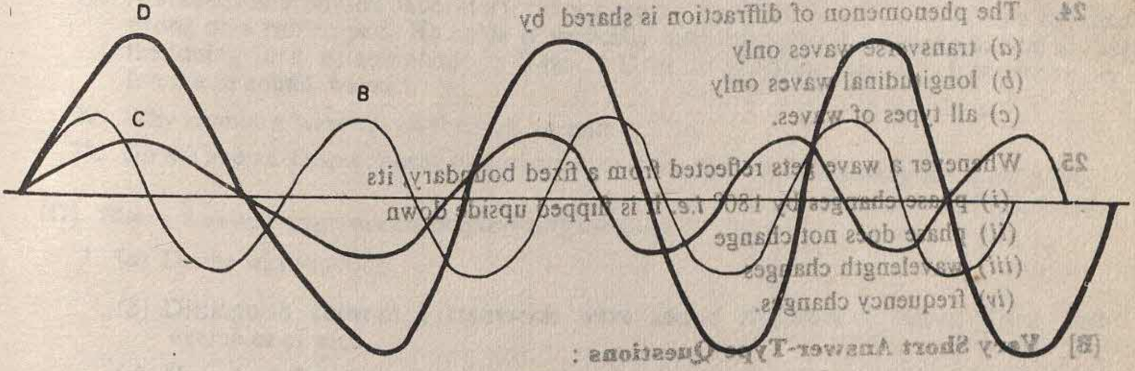


Fig. 3.43

20. In Fig. (3.44), two pulses are shown moving towards each other. When the two pulses coincide, the phenomenon which takes place is known as

(*i*) reflection

(*ii*) refraction

(*iii*) diffraction

(*iv*) interference

(*v*) polarization.

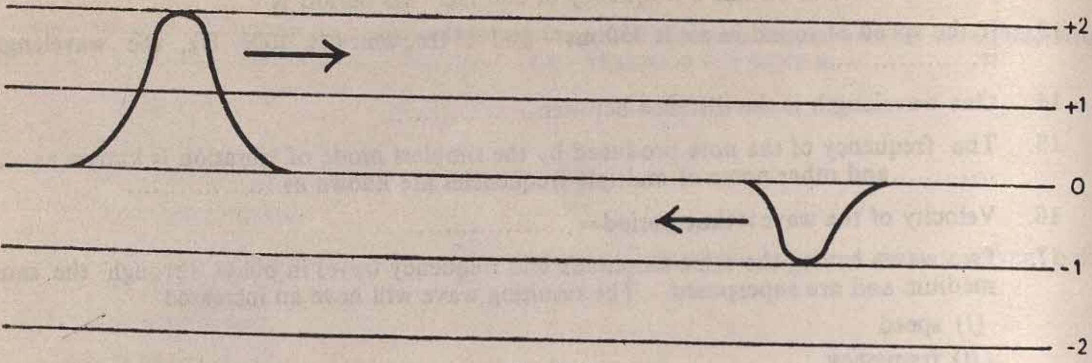


Fig. 3.44

21. When the two pulses in Fig. (3·44) coincide, the amplitude of the resulting pulse will be
    (*a*) +1
    (*b*) +2
    (*c*) +3
    (*d*) −1

22. ....wave can be polarized whereas..................wave cannot be polarized.

23. When a wave propagating in one medium is incident on another medium, its speed gets changed due to
    (*i*) reflection
    (*ii*) refraction
    (*iii*) diffraction
    (*iv*) polarization.

24. The phenomenon of diffraction is shared by
    (*a*) transverse waves only
    (*b*) longitudinal waves only
    (*c*) all types of waves.

25. Whenever a wave gets reflected from a fixed boundary, its
    (*i*) phase changes by 180° *i.e.* it is flipped upside down
    (*ii*) phase does not change
    (*iii*) wavelength changes
    (*iv*) frequency changes.

[B] Very Short Answer-Type Questions :

1. Is a wave a disturbance or energy ?
2. What evidence can you think of to show that a wave transmits energy ?
3. What is one difference between a pulse and a periodic wave ?
4. A tuning fork vibrating in air sets the molecules in the air in motion. How does the frequency of vibration of these molecules compare with the frequency of the tuning fork ?
5 What is the definition of wavelength ?
6. Give S.I. unit of frequency of a wave.

7. What is the unit of wavelength in S.I. system ?
8. How are frequency of wave and its time-period related to each other ?
9. What are the two common classification of waves ?
10. What kind of a wave is sound : Longitudinal or transverse ? [*A.I.S.S. 1987*]
11. What kind of a wave is light ?
12. What are nodes ?
13. What are antinodes ?
14. Mention the relationship between speed of wave, its frequency and its wavelength.
15. How does the spread of diffraction of a wave depend upon the width of the slit ?
16. How does the spread of diffraction of a wave depend upon the wavelength of a wave ?
17. What happens to a wave while going from a rarer medium meets the surface of a denser medium ?
18. What is the definition of *refraction of a wave* ?
19. Can a longitudinal wave be polarized ?
20. Does the phenomenon of *interference* of waves violate the principle of conservation of energy ?
21. Mention one condition for the interference of waves to take place.
22. Two vibrating particles in a wave motion are *in phase*. What does it mean ?
23. What is a straight wave ?
24. What is a circular wave ?
25. What is a plane polarized wave ?
26. A student in a physics laboratory takes a tuning fork and sounds it by hitting any one prong on a rubber pad. He holds it vertically near his ear and turns the handle so that the tuning fork rotates about its length. Does the vibrating tuning fork produce interference in sound waves ?
27. Why cannot a wave travel through vacuum ?
28. On a Time *vs.* Displacement plot of a wave, mark three points having the same phase. [*A.I.S.S. 1987*]

[C] Short Answer-type and Essay-type Questions

1. (*a*) Define wave-motion.

   (*b*) **Distinguish between a transverse wave and a longitudinal wave. Give three examples of each.**

   (*c*) **How does the motion of the particles of a medium differ from the motion of the wave through it ?**

2. (*a*) **Define the following terms with reference to a wave-motion :—**

   Vibration (or oscillation) ; time-period ; frequency ; amplitude : Wave-length and phase of a vibrating particle.

   (*b*) Derive the relationship between the time-period and frequency of a wave.

   (*c*) Derive relationship between wave-length ; frequency and velocity of a wave-motion.

3. Explain the following terms :

   (*i*) Compression (or condensation) (*ii*) Rarefaction

(*iii*) Crest
(*iv*) Trough
(*v*) Nodes
(*vi*) Antinodes (or loops)

4. What is a wave motion ? Give some of the characteristics of a wave motion.

5. (*a*) Define : Stationary (or Standing) waves ; Nodes and Antinodes.
   (*b*) Distinguish between standing waves and progressive waves.
   (*c*) What is the difference between :
      (*i*) two consecutive nodes
      (*ii*) node and an anti-node
      (*iii*) two consecutive antinodes
   (*d*) Give two examples of stationary waves.

6. State the principle of superposition of waves. How does this principle help in explaining the following phenomena :
   (*i*) Interference of waves
   (*ii*) Standing waves

7. (*a*) Is sound wave in air a transverse wave or a longitudinal wave ?
   (*b*) How will you explain the propagation of a sound wave in air ?
   (*c*) The steam of a railway engine is seen first and the whistle is heard a little later. Why ?
   (*d*) A tuning fork is marked with the number 512. What does this number signify ?

8. How do you distinguish between a pulse and a periodic wave ? Give examples.

9. When a wave is generated in a pond, is it the water or the wave or both which travel ? Describe an experiment to support your answer.

10. How do transverse waves differ from longitudinal waves ? Describe an experiment which can distinguish between the two.

11. Explain the priciple of superposition of waves. Describe what happens when two waves on a rope moving in opposite direction cross each other.

12. Explain the phenomena of *interference* and *diffraction*. Do you observe these phenomena with transverse waves or with longitudinal waves or with both ? Give examples.

13. How are standing waves produced ? What is the maximum wavelength of a standing wave on a string of length L ?

14. Describe two experiments, one each to explain the phemonena of reflection and refraction of waves.

15. What kind of a wave is sound ? What variables can be used to represent a sound wave as a sine curve ?

16. (*a*) Under what conditions do two waves interfere with each other constructively ?
    (*b*) What are two other ways of saying that two waves are of opposite phase ?
    (*c*) When will two waves from two point sources annul each other ?

17. What is meant by diffraction of a wave ? How will you demonstrate it with the help of a ripple tank ? Why do sound waves exhibit this phenomenon prominently whereas it is not ordinarily observed in case of light waves ?

18. Explain the phenomenon of interference of waves in a medium. How will you demonstrate it with the help of a ripple tank.

19. Describe a ripple tank. How would you use it to study
(*i*) reflection of waves (*ii*) refraction of waves ?

20. How will you demonstrate the phenomenon of refraction of waves with the help of two strings of different densities ?

21. Explain the phenomenon of polarization of waves. How will you demonstrate it ? Do we consider light waves to be transverse or longitudinal ? [*A.I.S.S. 1987*]

22. How does speed of a wave in a medium affect the amount of refraction of a wave ?

23. How does a pulse on a taut string differ from the incident pulse after being reflected at a fixed termination ?

24. List the common properties of waves and give an illustration of each.

25. Make a drawing showing two transverse waves of the same wavelength but of different amplitudes, which are in phase. Graphically find the wave pattern which results if these two waves are superposed.

26. Repeat Question 25 with waves of the same amplitude, but with one having twice the wavelength of the other. At $t=0$, the displacement of both waves is zero. At $t=T/4$ later for each, the displacement is maximum positive.

27. Repeat Question 26, but take the displacement as zero for the wave of longer wavelength, and as positive maximum for the wave of shorter wavelength at $t=0$ while the reverse applies at $t=T/4$.

28. In your drawings of Questions 26 and 27 mark the points of maximum displacement and zero displacement. Do they occur at the same points at $t=0$ as at $t=T/4$? Would you consider the resulting pattern as a standing wave or a progressing wave ?

29. What are the requirements for production of a standing wave pattern ?

30. When two waves interferere, what influence does each exert on the progress of the other ? Explain.

31. When two waves interfere, is there a loss of energy in the system ? Explain.

32. Two rooms are separated by a special sound-proof partition except for a connecting doorway. How can you explain the fact that a sound produced anywhere in one room can be heard anywhere in the other ?

33. A new phenomenon has been observed in which there is a transfer of energy. What type of experiment would you propose to determine whether it is a particle or wave phenomenon ?

34. (*a*) In what ways may energy be transferred ?
(*b*) What is a disturbance ? What constitutes the disturbance when a wave moves across the surface of a pond ? What constitutes the disturbance when a longitudinal wave travels through the air ?
(*c*) What does a wave source supply to the medium through which the wave passes ?

35. In an experiment, it is found that when two identical bodies are vibrated together, no sound is heard at some points. Explain how. [*A.I.S.S. 1987*]

36. What is the basic difference between light and X-Rays ? [*A.I.S.S. 1987*]
[**Hint** : Both are waves but differ in **wavelength**.]

PROBLEMS

1. What is the period of a sound wave with a frequency of $2\cdot5 \times 10^{3}$ Hz ? [**Ans.** 4×10^{-4} s]

2. What is the frequency of a light wave with a period of $1\cdot6 \times 10^{-15}$ s ? [**Ans.** $6\cdot25 \times 10^{14}$ Hz]

3. What is the wavelength of a lightwave with a period of $1\cdot6 \times 10^{-15}$ s ? Velocity of light wave in air is 3×10^{8} m/s. [**Ans.** $4\cdot8 \times 10^{-7}$ m]

4. The pendulum of a grandfather clock makes the floor vibrate with a period of ½ sec. What would be the wavelength in air of the sound generated by this vibration. (Velocity of sound in air $= 3\cdot4 \times 10^{2}$ m/s). [**Ans.** $1\cdot7 \times 10^{2}$ m]

5. Assuming that the lowest audible note has a frequency of 16 s^{-1}, and the highest audible note has a frequency of 2×10^{4} Hz, find the corresponding wavelengths in air. Take the velocity of sound in air to be $3\ 4 \times 10^{4}$ cm s^{-1}. [**Ans.** $21\cdot5$ m ; $1\cdot7 \times 10^{-2}$ m]

6. A mass at the end of a horizontal spring is stretched $0\cdot050$ m from its rest position and then released. If it takes $1\cdot0$ s for the mass to move through its rest position to an extreme position in the opposite direction,

   (*a*) What is the amplitude of the motion ?

   (*b*) What is the amplitude of the vibration ? [**Ans.** (*a*) $0\cdot050$ m (*b*) $0\cdot50$ Hz]

7. A tuning fork is marked with the number 500. What does this number signify ? What is the frequency of this tuning fork ? Calculate the wavelength of the sound wave produced by it. Velocity of sound $= 340$ ms^{-1}. [**Ans.** 500 Hz ; 0 68 m]

8. A body vibrating with a certain frequency sends waves $0\cdot15$ m long through a medium *A*, and $0\cdot20$ m long through a medium *B*. The velocity of wave in $A = 120$ cm/s. Find the velocity of wave in *B*. [**Ans.** $1\cdot6$ m/s]

9. If the highest note which a human ear can hear corresponds to a frequency of 30 kHz, find the shortest wavelength which it can detect. Velocity of sound in air $= 340$ ms^{-1}. [**Ans.** $1\cdot13 \times 10^{-2}$ m]

10. A wave has a wavelength of 4 m and frequency of 200 Hz. Find its time-period and velocity. [**Ans.** $0\cdot005$ s : 800 m/s]

11. A man sets his watch by the noon whistle of a factory at a distance of 1 km. How many seconds is his watch slower than the time piece of the factory ? Velocity of sound $= 332$ ms^{-1}. [**Ans.** $3\cdot01$ seconds]

12. If the frequency of a tuning fork is 400 Hz and the velocity of sound in air is 320 ms^{-1}, find how far sound travels while the tuning fork executes 30 vibrations [**Ans.** 24 m]

13. What is the speed of a periodic wave disturbance, frequency $2\cdot5$ Hz and wavelength $0\cdot6$ m ? [**Ans.** 1 5 m/s]

14. Calculate the wavelength of water waves which have frequency $0\cdot50$ Hz and speed $4\cdot0$m/sec. [**Ans.** 8 m]

15. The speed of transverse waves in a string is 15 m/s. If a sourcee produces a disturbance, frequency $5\cdot0$ Hz, what is the wavelength of the wave produced. [**Ans.** 3 m]

16. A periodic transverse wave, frequency 10·0 Hz, travels along a string. The distance between a crest and either adjacent trough is 1·50 m What is (*a*) the wavelength, (*b*) the speed of the wave ? [**Ans** (*a*) 3 m (*b*) 30 m/s]

17. A periodic longitudinal wave, frequency 20 Hz, travels along a coil spring. If the distance between successive compressions is 0·40 m, calculate the speed of the wave. [**Ans.** 8 m/s]

18. What is the wavelength of a periodic longitudinal wave in a coil spring, frequency 8·0 Hz, and speed 20 m/sec ? [**Ans.** 2·5 m]

19. A wave generator produces 16 pulses in 4·0 seconds (*a*) What is its period ? (*b*) What is its frequency ? [**Ans.** (*a*) 0·25 s (*b*) 4 pulses/second]

20. One pulse is generated every 0·10 sec in a tank of a water and the wavelength of the surface wave measures 3·3 cm. What is the propagation speed ? [**Ans.** 33 cm s^{-1}]

CHAPTER 4

Sound

4.1. INTRODUCTION

Many of our greatest pleasures—friendly conversation around the dinner table, the rustle of autumn leaves, the boom of the ocean surf, a song by a favorite recording artist, singing ; drumming ; playing a musical instrument ; the radio producing music—come to us by sound waves striking our ears. In this chapter we will apply the ideas about waves developed in the preceding chapter to sound waves, to see how they are produced, with what speed they travel and what are their characteristics. We will also discuss the miracle of the human ear and its exquisite sensitivity to the sounds which surround us.

4.2. PROPAGATION OF SOUND WAVES

In the preceding chapter we saw that a sound wave is a longitudinal wave consisting of periodic variations in the displacement of the particles of the material and in the pressure, parallel to the direction in which the wave is travelling. It travels in the form of compressions and rarefactions.

When your teacher speaks to you, you hear him easily, which means that at least air can carry sound.

Have you played with a toy telephone before, *i.e.*; two match-boxes connected by a long string with two boys standing either end. This shows without doubt that sound can pass through a string (Fig. 4.1).

If you place your watch at one corner of a long table and your ear against the table at the opposite corner you will hear the ticking of the watch quite distinctly, whereas if you place the watch at an equal distance in air you will not be able to hear its ticking. This again shows that wood can carry sound.

Have you read the story of how scouts listened to sounds of soldiers marching many kilometers away by placing their ears against the ground (Fig. 4.2)? The earth is therefore a carrier of sound.

While swimming in water have you ever tried to listen to a sound, *e.g.*, clapping, produced under water? The sound will be heard very distinctly, showing that water also carries sound.

Now try the following experiment.

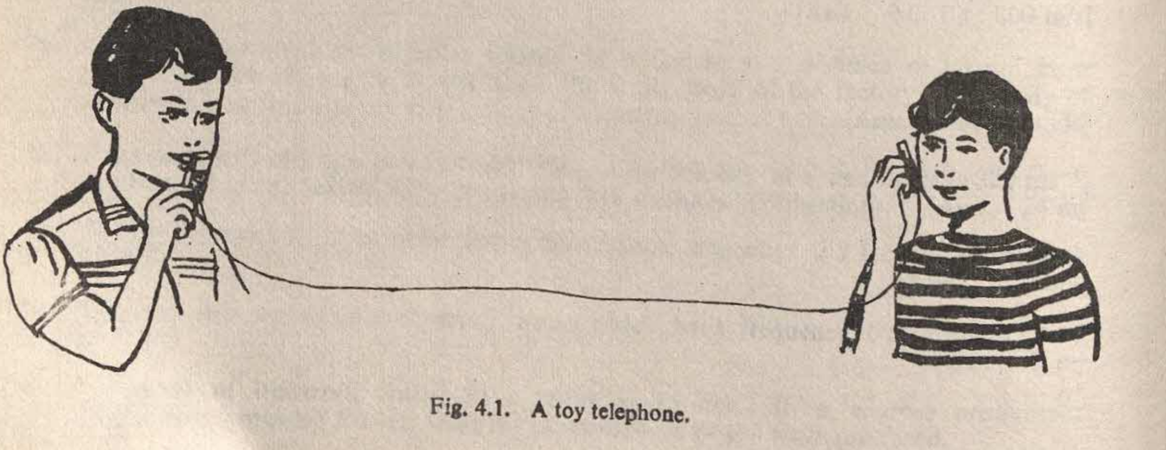


Fig. 4.1. A toy telephone.

Fig. 4.2. A scout listening for enemies.

Experiment. *To find out if sound can pass through a vacuum.*

Requirements. Bell jar with glass plate to cover it, vaseline, electric bell, battery, connecting wires, key and exhaust pump.

Procedure. Place the bell jar upside down on the glass plate and seal the junction with vaseline. Connect the tube shown (See Fig 4.3) to an exhaust pump and the terminals of the electric bell, which has been safely placed inside the jar, to a battery and a key. Press the key and listen to the ringing of the bell.

Now use the exhaust pump to pump air out of the bell jar. Continue to pump air out until there is hardly any left in the jar. Keep the key closed all the time and listen to the ringing of the bell. What have you noticed?

As the air is gradually removed, the sound becomes less and less until no more sound is heard.

This shows simply that a vacuum *does not carry sound.*

We are now in a position to say generally that sound is carried by solids, by liquids and by gases, but not by a vacuum. In other words, sound requires something—a *material medium*—to carry it and since a vacuum contains nothing whatever, sound cannot pass through it.

On the moon, which has no atmosphere, the astronauts could hear no sound except that communicated through the solid surface of the moon (or through radio waves).

Sound waves propagate readily through all forms of matter—solids, liquids, and gases

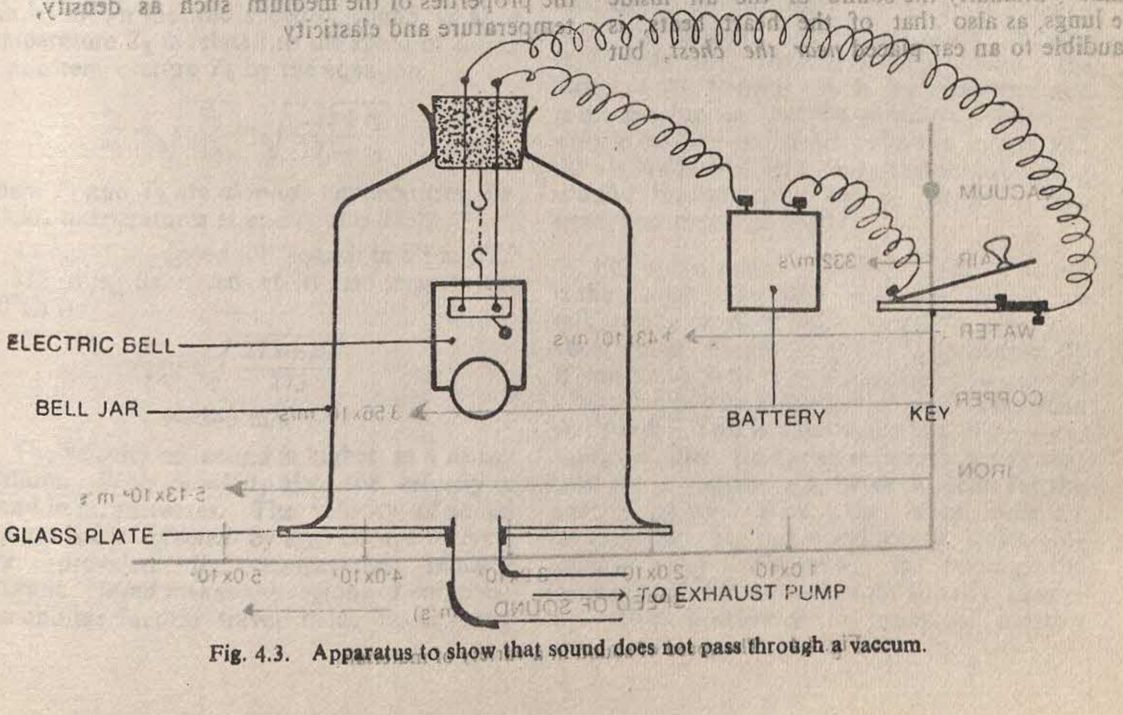


Fig. 4.3. Apparatus to show that sound does not pass through a vaccum.

alike. Sound propagates better through solids than through gases, for in solids there are more molecules per unit volume to carry the sound. For the same reason sounds appear louder under water than they do in air, since the liquids conduct sound better because of their greater density.

If the ear is applied to one end of a long board while some one lightly knocks at the other end, the sound of the knock will be heard distinctly, though it may cease to be audible when the ear is no longer in contact with the board. This shows that sound does not readily pass from the board into the air. Similarly, it does not pass readily from air into water ; for a diver inside cannot hear the shouts of people outside the water. In general, we may say that sound does not readily pass from one medium to another when the two differ greatly in density. This explains why ear must be applied to the rails to listen for an approaching train. The sounds made by the wheels pass readily through the rails but not from the rails to the air. Again, the sound of water, running in the mains under the street is inaudible to us but the water company's inspector, by applying a rod to the ground above the pipe and pressing the ear to the other end of the rod can hear the water running because there is a continuous solid connection from the pipe to the ear. He can thus detect any leaks in the mains. Similarly the sound of the air inside the lungs, as also that of the heart beats, is inaudible to an ear placed *near the chest*, but can be readily heard if the ear is *pressed on to the chest*. The doctor uses a *stethoscope* to make a solid connection between the chest and the ear and these sounds thus become clearly audible to him.

This principle is usually made use of in preventing sound from passing from one place to another. Houses are usually built with walls, having an air space between two facings of bricks, with the result that sound cannot pass readily from one room to another. In houses with solid walls, however it can easily do so. For the same reason, double windows are used in offices, situated in noisy surroundings.

4.3. HOW FAST DOES SOUND TRAVEL ?

(Speed of Sound)

During thunderstorms we see the lightning long before hearing the thunder, even though they are both produced at precisely the same instant. Also when a gun is fired to start a race we see the smoke far off before we hear the sound of the firing. In the same way the puff of steam is seen from a far off train before the sound from its whistle reaches us. All these go to show that sound takes some time to travel from place to place, that is, it has speed. It also shows that the speed of light (3×10^8 m/s) is much greater than that of sound. The speed of sound waves depends on the properties of the medium such as density, temperature and elasticity

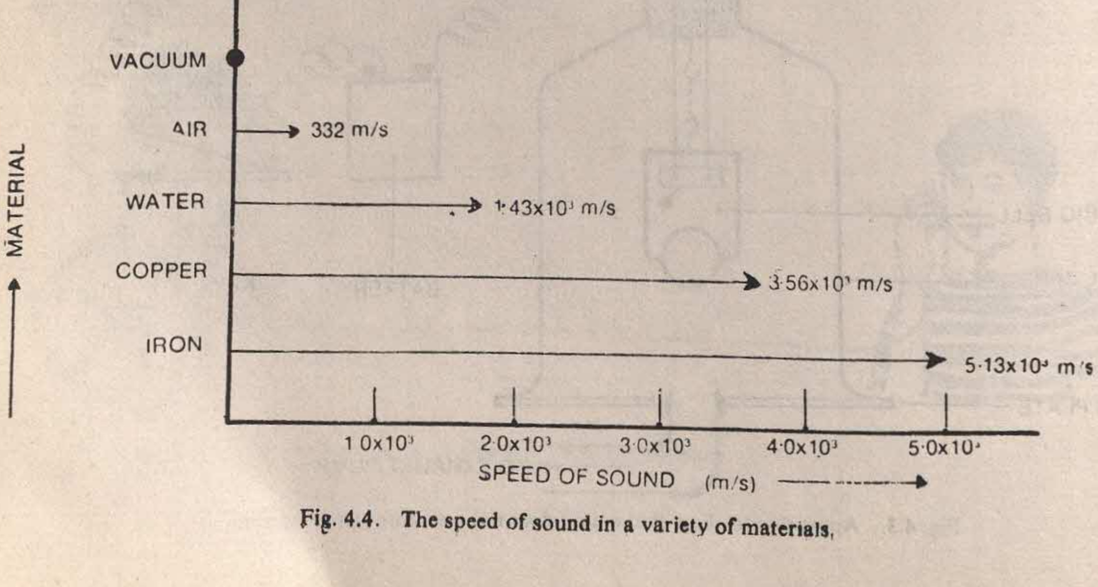


Fig. 4.4. The speed of sound in a variety of materials.

Table—4.1. Speed of Sound in a Variety of Materials

Material	*Speed of sound (m/s)*
AIR (STP)	332
Carbon dioxide (STP)	258
Hydrogen (STP)	$1{\cdot}27\times10^3$
Water	$1{\cdot}43\times10^3$
Mercury	$1{\cdot}45\times10^3$
Aluminium	$5{\cdot}10\times10^3$
Copper	$3{\cdot}56\times10^3$
Iron	$5{\cdot}13\times10^3$
Nickel	$4{\cdot}97\times10^3$
Tungsten	$4{\cdot}32\times10^3$

Figure 4.4 and Table 4.1 show the speed of sound in a variety of materials. We see that the sound travels more rapidly in liquids (say water) than in gases (say air) and more rapidly in solids (say metals) than in liquids. The speed of sound in dry air and at 0°C is 332 m/s. The speed of sound varies little with temperature for liquids or solids. In gases, however, the dependence is considerable. It can be shown that the speed of sound v_1 at a temperature T_1 is related to the speed of sound v_2 at a temperature T_2 by the equation.

$$\frac{v_1}{v_2}=\sqrt{\frac{T_1}{T_2}}=\sqrt{\frac{273+t_1}{273+t_2}}$$

where T_1 and T_2 are *absolute* temperatures, *i.e* celcius temperatures t_1 and t_2 plus 273°.

Hence if the speed of sound in air at *STP* is 332 m/s, its speed at room temperature (20°C) is

$$\frac{v}{332}=\sqrt{\frac{273+20}{273}}$$

or $$v=343 \text{ m/s}$$

The velocity of sound is higher in a *denser* medium. With *humidity* also, the velocity of sound in air increases. The velocity of sound in a gas is *not affected* by any *change in pressure*, provided the temperature remains constant. *Wind* makes the regions of compression and rarefaction travel much faster along its own dirertion and slower against it. Thus if wind blows with a velocity W in the same direction in which the sound travels with a velocity v in the absence of the wind, the resultant velocity of sound becomes $(v+W)$. If however, the wind blows in the direction opposite to that in which the sound travels, the resultant velocity of sound is given by $(v-W)$.

4.4. SOME SOURCES OF SOUND

Try to listen to various sounds, trace each one back to its source and find out what is happening to produce the sound. As examples, find out and write down how each of the following produces sound :

a drum ; a guitar ; a piano ; a sitar ; a whistle ; the whistling tree ; the human voice box ; the tuning fork ; the radio ; a violin ; a loudspeaker ; a cymbal ; a tabla.

Can you see anything in common in the ways the objects listed above produce sound ?

None of the instruments will produce any sound unless it is either beaten or struck or bowed or blown. When thus treated it starts moving rapidly and the movement produces sound. **Thus, sound is produced by vibration or movement.**

The thin leather of the drum is beaten or hammered, and it moves up and down, *i.e.* it vibrates, produces sound ; a guitar is plucked with the fingers, the string starts moving rapidly to and fro, producing sound ; the string of the piano is struck by a hammer and is set moving to and fro producing sound ; a whistle or flute is blown with the mouth and the air inside it is set moving rapidly producing sound ; the whistling tree is moved by the wind, and produces sound.

For us the most important source of sound is the *human voice box* or *larynx*. When we talk or sing or make any sound, we make our vocal cords vibrate [Fig. (3.12) in chapter-3]. If you touch your throat gently, you can feel a hard lump which moves up and down when you speak. This is your voice box. Two vocal cords are stretched across it in such a way that it leaves a narrow slit between them for the passage of air. When the lungs force air through the slit, the vocal cords vibrate producing voice. However, in talking, the frequency of the sound is continuously changing. This is achieved by means of muscles attached to the vocal cords in the voice box. When you emit a high frequency sound, the muscles stretch the cords very tightly. On the other hand, when you emit a low frequency sound, the vocal cords are loose and thick.

Several objects move either so slowly or so rapidly that the ear is not able to hear the sound produced by them. A ruler fixed at one end and plucked at the other will move to and fro, but may not produce sound which can be heard. The vibration is too slow. A bat also squeaks, but the sound it produces is caused by such a rapid vibration that our ears can not detect it.

4.5. CHARACTERISTICS OF A SOUND WAVE

Sounds are usually divided into two classes, *musical notes* and *noises.* Sounds which produce a pleasing effect upon the ear are known as musical sounds, much as those produced when we bow a violin string or play upon a flute and other musical instruments On the other hand sounds which are not pleasing to the ear are classed as noises, such as those produced during the explosion of a mixture of hydrogen and oxygen or by clapping two blocks of wood together or by breaking glassware on the ground etc.

A musical sound is produced by regular vibrations with no sudden changes in amplitude whereas noises are produced by irregular vibrations. We can tell the difference between one musical note and another in three ways, namely ; by their **loudness**, their **pitch** and their **quality or timbre**. These three properties of a musical note are known as its *characteristics.* In a noise these characteristics are not clearly defined.

(*a*) **Loudness**. When you strike the note of a piano gently you will hear a feeble sound but when you strike the same note with a greater force you will hear a louder sound. This shows that the loudness of the note depends on the force with which the note is hit. You can notice the same effect in your voice ; you require a greater effort to speak loudly than to speak softly. Greater the force greater is the amplitude of vibration. The more you stretch the string of a *sitar* or *tanpura,* the greater will be the amplitude of vibration of the string and louder will be the sound produced. Thus loudness of sound depends on the amplitude of the sound waves—greater the amplitude, louder the sound. It is measured in terms of energy carried by sound waves. In other words, it is associated with the **intensity of sound** *which is measured by the amount of sound wave energy crossing per second per unit area held perpendicular to the direction of propagation.* It is important, therefore, to note that though the intensity of sound and loudness are related to each other, they are not the same. Whereas the intensity of sound depends entirely on the energy associated with a unit area of the sound wave the loudness depends both on the energy and the response of the ear. The intensity of a sound wave is an objective property which can be measured quantitatively by instruments. The loudness of a sound, on the other hand, is a *subjective property* which depends on the nature and condition of the ear doing the hearing. Also, the loudness of a sound may vary markedly from individual to individual depending on age, sharpness of hearing, amount of wax in the ears and other subjective factors. The intensity of a sound wave is proportional to the square of the amplitude of the vibrating particles in the medium and to the square of the frequency. The intensity also depends on the density of the material.

(*b*) **Pitch.** This is an important characteristic of a musical sound and enables the ear to distinguish between *high* and *low, acute* and *grave, sharp* and *flat* sounds though of the same loudness. A musical note produced by *slow* but audible vibrations is said to be of *low pitch* while one of *fast* but audible vibrations is said to be of *high pitch.* For instance, the notes on the left end of a piano are of low pitch, while those on the right end are of a high pitch. Roaring of a lion is of low pitch whereas a woman's voice is of higher pitch. When two notes have the same frequency of vibration, their pitch is the *same* and they are said to be in *unison.*

It can, therefore, be said that the pitch of a note depends on how quickly or how slowly an object is vibrating ; faster it vibrates, the higher the pitch. It should be clearly understood that **pitch is not the same thing as frequency, but it is a sensation which depends upon frequency.** Frequency is the fundamental physical property which indicates the number of oscillations of a vibrating body. The perceived physiological response to the frequency of a sound wave is called the pitch.

A very simple experiment to show that pitch depends upon frequency is as follows :

Take a metal disc having a large number of teeth along its circumference mounted in such a way that it can be rotated at various speeds by a handle. The metal disc is turned at a gradually increasing rate, while the edge of a cardboard is held against the teeth. At first, when the speed is low, the taps are heard as separate. But as the speed of rotation increases, the taps succeed each other very rapidly and ultimately blend into a musical note, whose pitch increases as the metal disc is made to rotate more quickly. In this experiment, the cardboard is made to vibrate by the teeth and the number of vibrations it makes per second depends on the speed of the metal disc. Hence we conclude that the pitch of a note is determined by the frequency of the vibrating body. That the pitch of a note depends upon its frequency can also be shown by an instrument called the *siren*. At low speeds, the puffs are heard separately but, at a sufficiently high speed, they blend together into a musical note whose pitch rises as the speed increases.

Take a tuning fork. The number written on it is the frequency with which the tuning fork vibrates when struck against a rubber pad. As we know, frequency is measured in hertz (Hz). One hertz is one vibration per second. If we vibrate tuning forks with different frequencies, we should be able to distinguish between the different sounds. The differences arise because of the differences in pitch. Some people can distinguish two notes differing only by a few hertz. The human ear can hear notes of as low a pitch as 20 Hz. The sensitiveness of the ear to notes of higher frequencies decreases as the age advances. Children can hear notes with 20000 Hz whereas older people cannot hear sound with frequencies above 15000 Hz. The frequency range from 20 Hz to 20000 Hz which produces the sensation of hearing is called the *audible range*. Waves with frequencies above the audible range are called *ultrasonic waves* and those with frequencies below the audible range are called *infrasonic waves*. Whereas we can hear sound with frequencies upto 20000 Hz, dogs can hear over a much wider range (15–50000 Hz) and bats can hear upto 120000 Hz. Infrasonic waves are usually produced by large sources. Waves originating from earthquakes are examples of infrasonic waves.

(c) Quality or Timbre This is the characteristic of sound that enables us to know what particular instrument is producing the sound. Several instruments may sound a note of the same pitch and loudness, yet if you shut your eyes you will be able to tell which instrument is producing a particular note. You are also able to tell without looking which of your classmates is talking or singing, even though they may be talking or singing the same thing. All this is because the quality of the note is different for different sources of sound. The sounds produced by musical instruments are *never pure* but are generally mixed up with other notes of higher frequencies, which are simple multiples of their *lowest* or *fundamental* notes and called *overtones* or *harmonics*. If the fundamental frequency is n, the next harmonics are $2n$, $3n$, $4n$.......

Thus we conclude that *quality* or *timbre* is that characteristic of a musical sound which enables the ear to distinguish between two notes of the same pitch and intensity (or loudness) and it depends upon the presence of overtones or harmonics.

4.6. EAR AS AN INSTRUMENT OF HEARING. (How do we hear sound ?).

Figure (4.5) is a drawing of the human ear. The ear collects the sound and we hear it. It performs the same function as a microphone but in a much more complicated and delicate fashion. There are three parts to the ear : the external ear, the middle ear or drum, and the external ear (see Fig 4.5). The external ear acts as a funnel, collecting the sound. The sound then strikes the drum, which begins to vibrate. The message now goes to the internal ear, which passes it to the brain through the auditory nerves in the form of electric signals.

The outer ear contains the ear canal, which is about 2.7 cm long and ends at the eardrum. The middle ear transmits the sound from the eardrum to the oval window which separates the middle ear from the inner ear. The sound is transmitted by three tiny bones (ossicles), the *hammer*, *anvil* and *stirrup*, which act as a lever system to multiply in the transmission process the force applied to the eardrum by a factor of about 2. The *pressure* at the oval window is increased by a factor of about 40 with respect to that on the eardrum, however, because the area of the oval window is 20 times smaller than the area on the eardrum. [From equation, Pressure $(P) = \frac{\text{Force}\ (F)}{\text{Area}\ (A)}$ and here the force is transmitted unchanged (or slightly increased) by the ossicles, and so the pressure varies inversely as the ratio of the two areas. Since

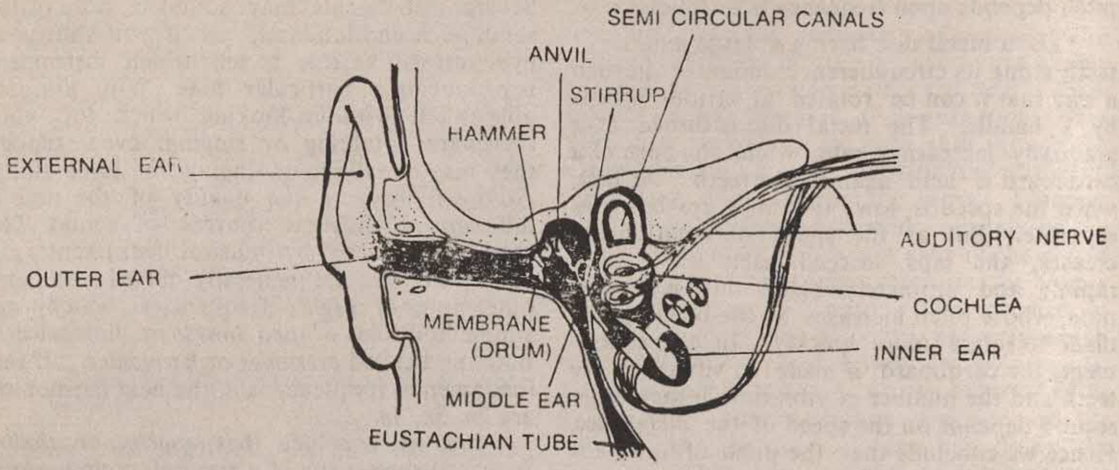


Fig. 4.5 The Human Ear

the area of the oval window is 20 times smaller than that of the eardrum, the pressure increases by the same factor.]

The inner ear contains the semicircular canals which are important for maintaining balance, and the *cochlea*, a snail-shaped cavity filled with a liquid called *lymph*. The stirrup presses on the oval window and sets up sound vibrations in the lymph. Thirty thousand sensory cells (*organs of corti*) located on the partition which divides the cochlea into two parts detect the sound vibrations in the lymph and pass on the signal (nerve impulses) to the auditory nerve fibres, which carry them to the brain where they are perceived as sounds.

Because this process is rather complex and incompletely understood, we will not dwell further on it here.

The ear is an extremely sensitive detector of sound, as good as the most sensitive microphones made. Thus a displacement of the eardrum by only 10^{-11} m (smaller than the average diameter of an atom, which is about 2×10^{-10} m) can give rise to a sound which the normal human ear can hear.

Defective hearing can be due to a breakdown at any point in the ear's complicated sound-transmission system. Hearing aids can sometimes help those hard of hearing. These are basically combinations of a microphone and an amplifier which boost the sound level at the eardrum and thus compensate for defects in the ear structure itself.

As mentioned earlier, the human ear can pick up vibrations lying within the range of 20 to 20000 Hz. It can tell the difference between sounds and can also pick up a single sound from a collection of sounds being produced the same time.

4.7. RESONANCE—(air Columns)

Every vibrating body has got a *natural frequency* of its own. This is the frequency with which it vibrates of its own with no external force acting on it after it is set into vibrations. This frequency depends on many factors, *e.g.* its length, thickness, density of its material, etc.

When a body vibrates with its natural frequency, it is said to execute free vibrations.

The strings of musical instruments like violin, guitar, sitar, a tuning-fork and membrane of a drum have their natural frequencies. The top of a table also has a natural frequency with which it vibrates and produces sound when tapped, though this sound lasts for a short time.

It is possible, however, for one vibrating object to impress its frequency upon another that has a different natural frequency. When we hold the stem of a vibrating tuning-fork against a table, we listen louder sound of the same frequency as that of the tuning-fork. In fact the tuning-fork impresses its frequency upon the table-top. Energy is transmitted through the stem of the fork, and the table is forced to vibrate in response to the periodic force thus applied. Such vibrations are called *forced vibrations.*

When a body is maintained in a state of vibration by a periodic force of time period different from its own time period, it is said to execute **forced vibrations.**

Consider now two tuning forks of the same frequency (say 512) mounted on two identical hollow boxes and held by two students at some distance from each other. Let one student vibrate his tuning-fork and after some time, stop it by touching the prongs. The other student will discover that the fork which he holds is now vibrating feebly (Fig. 4.6). The impact of compressions and rarefactions from the first fork fell upon the second fork in regular succession and caused it to vibrate sympathetically. These occur when the natural frequencies of the two objects are the same.

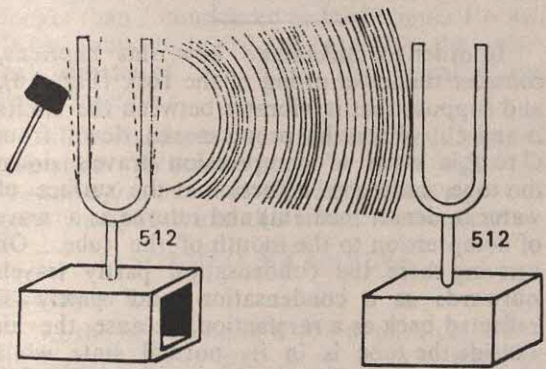


Fig. 4.6 Resonant vibrations in a tuning fork.

After observing these vibrations as described above, let the second student change the natural frequency of his tuning-fork by putting some wax on its prongs. The above experiment is then repeated. After the first student stops his tuning-fork, the second will not find his tuningfork vibrating. Why does it not vibrate now by the impact of compressions and rarefactions which fall on it ? In fact, it vibrates and executes forced vibrations. But these vibrations are feeble, so much so that no sound is heard by the second student. The forced vibrations are the largest and produce the loudest sound when the frequency of the second tuning-fork is *equal* to that of the first one. This phenomenon is called *resonance.* The resulting vibrations are called *resonant vibrations or sympathetic vibrations.*

When a body is maintained in a state of vibration by a periodic force of time period equal to its own free period, it is said to execute **resonant vibrations** and the phenomenon is called **RESONANCE**. It is a special case of forced vibrations.

Soldiers crossing a suspension bridge are always asked to break step. If they start marching across the bridge in step, the frequency of their step may agree with he natural frequency of the bridge. In that case, the bridge structure may be set into violent and dangerous resonant vibrations and may even come crashing down.

If we sing a loud note into a piano and then bring our ear close to it, the strings having their natural frequencies equal to the frequency of the note will be found to be set into vibration. Similarly, a glass tumbler or a piece of china-ware on shelf is set into resonant vibrations when some note is being sung or played.

Sometimes a brisk rattling sound appears in an automobile running at a particular speed but if the speed changes a little, the sound disappears. The sound is due to the resonance taking place between the car engine and the rattling object.

Several toys have been constructed these days which respond to a particular word of command. Their action depends upon the phenomenon of resonance.

Vibrating air Columns

Let us take the cap of a fountain pen and blow at its mouth. It gives out a typical whistling sound. Another similar cap of a longer length gives a different sound. The whistle is given out because the air column inside is set into vibration.

The natural frequency of vibration of this type of the air column depends upon its length. It is such that the wavelength of sound in the case is four times the length of the air column. Thus, if the length of the air column is l,

$$\lambda = 4l$$

A column of air of an adjustable length can be obtained by having a long tube held vertically, which can be dipped in a large container full of water (Fig. 4.7). If a vibrating tuning-fork is brought near its mouth, forced vibrations are set up in the air column inside and the resulting sound may increase a little.

Let the above experiment be tried for different lengths of the air columns by gradually

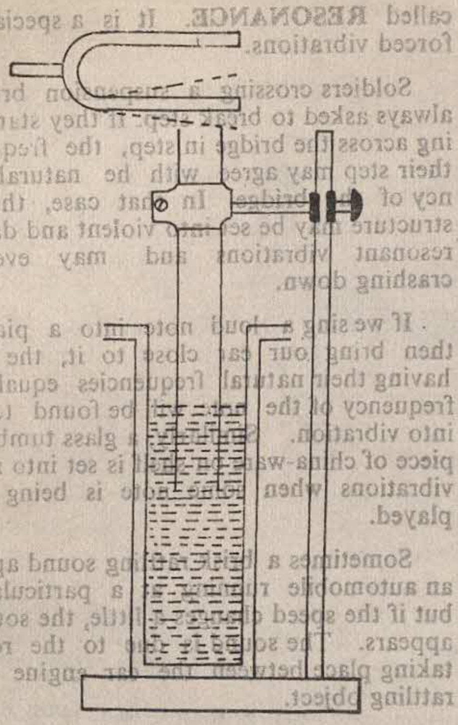


Fig 4.7. Resonating air column

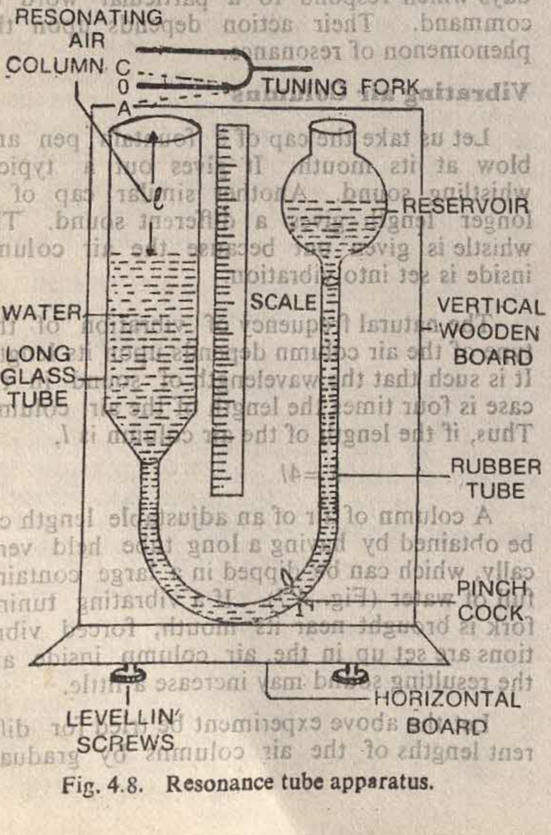


Fig. 4.8. Resonance tube apparatus.

raising the tube from its lowest position. At a certain length of the air column, the increase in sound of the tuning-fork will be distinctly louder than that at other lengths. At this length, the resonant vibrations have been set up and the frequency of the air column has become equal to that of the tuning-fork.

This experiment can be used to find the velocity of sound in the air within the laboratory by an apparatus as shown in Fig. 4.8. If the frequency (ν) of the tuning-fork is known and the length (l) of the air column which resonates with it is measured, the velocity (V) of sound in the air at room temperature can be found by the expression.

$$\boxed{V=4\nu . l}$$

In order to understand how this happens, consider the lower prong of the fork (Fig. 4.8), and suppose that it vibrates between the limits *A* and *C*. When the prong moves down from *C* to *A*, a wave of compression travels down the tube, undergoes reflection at the surface of water (a denser medium) and returns as a wave of compression to the mouth of the tube. On arriving there, the condensation partly travels outwards as a condensation and partly is reflected back as a rarefaction, because the air outside the tube is in its normal state while that inside the tube is in a state of compression and so the reflection here takes place at a comparatively rare medium. If the prong has by now reached *A* and is moving upwards towards *C*, it will also send a wave of rarefaction down the tube, and so the two waves of rarefaction will reinforce each other. This reinforced rarefaction travels down the tube and is reflected back as a rarefaction. When the rarefaction reaches the top, it is reflected down as a condensation and, if at this moment, the prong has reached *C* and is about to move down, it will also send a condensation downwards, thus reinforcing the condensation due to reflection. Hence motion of the fork and that of the air inside the tube coincide and produce *resonance.*

It is clear from the above that during the time the prong completes only half a vibration, the wave in the air column travels a distance equal to twice the length of the air column. Hence the wave travels four times the length of the air column during the time that the prong completes its one vibration. Since the distance that a wave travels in one time-period is equal to its wave-length, *it is clear that the wave length of the note is four times the length of the air column. i.e.,* $\lambda=4l$.

Since $V=\nu\lambda$, therefore, $V=4\nu l$.

If the length of the air column is increased by another one half wave length $\left(\frac{\lambda}{2}\right)$, resonance will occur again. In fact, we can continue to increase the length by half wave lengths and find resonance positions.

It was shown theoretically by Lord Rayleigh that the reflection of a wave at the open end takes place *not exactly at the end*, but a little way beyond it and so the effective length of the air column (l) must be taken to be a little longer than l considered in the formula $V=4\nu l$. It was found to be 0·3 D where D is the internal diameter of the tube. This is called the *end correction*.

All bodies have their natural frequency of ivbration. When we apply a small signal of the *same frequency* to the body, the signal is greatly amplified and this is called resonance.

SOLVED EXAMPLES

Example 1.

At the beginning of a 100 m dash the starting signal is a gun shot fired by a starter in line with the runners. There are eight lanes, each 1·22 m wide.

(*a*) What is the time delay between the starting signal heard by the sprinter in lane 1 and by the sprinter in lane 8 ?

(*b*) Could this have any effect on the outcome of the race ? 100 m can be covered in about 10 seconds by good sprinters.

[Velocity of sound in air at 20°C=340 m/s].

Solution

(*a*) The distance between lane 1 and lane 8 is $7\times1{\cdot}22$ m$=8{\cdot}54$ m

Since,

$$\text{Speed of sound}=\frac{\text{distance}}{\text{Time}}$$

$$\therefore \qquad \text{Time}=\frac{\text{distance}}{\text{speed of sound}}$$

$$=\frac{8{\cdot}54}{340}\mathbf{0\ 025\ s}$$

$\therefore$ The time delay between the signals reaching the two runners is 0·025 second.

(*b*) Since 100 m can be covered in about 10 s by good sprinters, their speed average is 10 m/s. Hence the distance corresponding to a time delay of 0·025 *s*

$$=0{\cdot}025\times10=0{\cdot}25\text{ m}$$

In a very close race this distance of almost a foot could well be decisive.

Example 2.

Resonance was observed with an air column when its length was 16 cm. If the frequency of the tuning fork is 512, calculate the velocity of sound.

Solution.

For the first resonance in air column we have, $V=4\nu l$

where V=Velocity of sound in air

ν=frequency of the tuning fork or that of the air column at resonance

l=length of the resonating air column.

Velocity of sound$=V=4\times512\times16$ cm/s

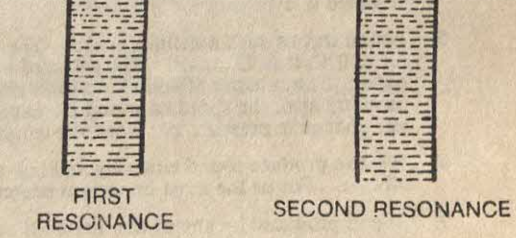
$=\mathbf{32768\ cm/s=327{\cdot}68\ ms^{-1}}$

Example 3.

A tuning fork is sounded above a tube filled with water. As the water level is changed, resonances are heard at two different points 34 cm apart. Given the velocity of sound to be 350 ms^{-1}, find out of frequency of the tuning fork.

Solution.

For the first resonance to take place, the length of the air column (l_1) must be $\frac{\lambda}{4}$ where



FIRST RESONANCE

SECOND RESONANCE

Fig. 4.9.

λ is the wave length of the sound emitted by the tuning fork. If the length of the column is increased by another $\frac{\lambda}{2}$ resonance will again occur. Therefore, the length of the air column (l_2) for second resonance to take place is

$$\left(\frac{\lambda}{4}+\frac{\lambda}{2}\right)=\frac{3\lambda}{4}\text{ (Fig. 4.9).}$$

$$l_2-l_1=\frac{3\lambda}{4}-\frac{\lambda}{4}=\frac{\lambda}{2}=34\text{ cm (Given).}$$

∴ $\lambda=34\times2=68\text{ cm}=0\ 68\text{ m}$

Velocity of sound $=V=350$ ms^{-1} (Given)

Frequency of the tuning fork $=\nu=$?

Since, $V=\nu\lambda$

$$\therefore \quad \nu=\frac{v}{\lambda}$$

$$=\frac{350}{0{\cdot}68}\text{ Hz}$$

$$\approx\mathbf{515\ Hz.}$$

Example 4.

Velocity of sound in iron is 5000 m/s. What is the wave length of sound of frequency (*i*) 20 Hz, and (*ii*) 20000 Hz ?

Solution.

(*i*) ∵ $V=\nu\lambda$

∴ $\lambda=\frac{V}{\nu}$; Here, $V=5000$ m/s

$\nu=20$ Hz

$$=\frac{5000}{20}\text{ m}$$

$$=\mathbf{250\ m}$$

(*ii*) $\lambda=\frac{5000}{20000}$ m

$$=\mathbf{0{\cdot}25\ m}$$

$$=\mathbf{25\ cm}$$

Example 5.

Two children are at opposite ends of an iron pipe. One strikes one end of the pipe with a stone. What is the ratio of times it takes the sound waves in air and in iron to reach the second child ? Velocity of sound in air is 344 m/s and velocity of sound in iron is 5120 m/s.

Solution.

The time necessary for a sound wave of velocity v to travel the length of the pipe l is found from $l=vt$ or

$$t=\frac{l}{v}$$

∴ The ratio of the times for air and iron is

$$\frac{t_{air}}{t_{iron}}=\frac{\frac{l}{v_{air}}}{\frac{l}{v_{iron}}}=\frac{v_{iron}}{v_{air}}=\frac{5120}{344}=\mathbf{14.9}$$

This means sound travels faster in iron (*i.e.*, in the denser material) than in air.

SUMMARY

1. When a body vibrates in air, it forces the molecules of air to vibrate with it. This produces longitudinal waves, which we call the *sound waves*.
2. The properties of sound waves depend upon the elasticity of air and are also called *elastic waves*.
3. Sound waves propagate through all the three types of media *i.e.* solids ; liquids and gases.
4. Material medium is essential for the transmission of sound and the loundness of sound depends upon the density of the medium in which it originates (and not on the density of the medium in which it is heard).
5. Sound travels with a definite speed. The speed of sound is different in different medium. In air at 0°C, it is 332 ms^{-1}. The speed of sound is *maximum in solids*, less in liquids and least in gases. The velocity of sound increases with the increase in *temperature* of the medium. With *humidity* also, the speed of sound increases. The velocity of sound in a gas is not affected by any change in pressure, provided the temperature remains constant.
6. We can produce sound either by making strings vibrate or by making plates and membranes vibrate. For us the most important source of sound is the human voice box.
7. Sound produced by any of the methods may be characterized essentially by three properties : *loundess* ; *pitch* and *quality*.

8. Loudness of sound depends on the *amplitude* of the waves—greater the amplitude, louder the sound.

   It is the perceived strength of a sound and is, therefore, measured in terms of the energy carried by sound waves.

9. *Pitch* is the perceived physiological response to the frequency of a sound wave. The pitch of sound is determined by the frequency of the vibrating body which gives out the sound.

10. The frequency range from 20 Hz to 20000 Hz which produces the sensation of hearing is called the *audible range*.

    Waves with frequencies above the audible range are called *ultrasonic waves* and those with frequencies below the audible range are called *infrasonic waves*.

11. *Quality* (or *Timbre*) is that property which enables the ear to distinguish between two musical sounds having the same loudness and pitch. It depends upon the presence of *overtones* or *harmonics*.

12.

Physical property	**Corresponding physiological property**
Intensity	Loudness
Frequency	Pitch
Harmonic content	Quality or timbre

13. We hear with our ears. The ear may be divided into three main parts: (*i*) the outer ear, (*ii*) the middle ear, and (*iii*) the inner ear.

14. Resonance in sound is a phenomenon of forced vibrations due to which sound waves can be produced with a large amplitude or intensity.

    All bodies have their natural frequency of vibration. When we apply a small signal of the same frequency to the body, the signal is greatly amplified and this is called resonance.

QUESTIONS

(A) Objective-Type Questions :

1. The speed of sound in metals exceeds its speed in air by about :
   - (*a*) One order of magnitude
   - (*b*) Two orders of magnitude
   - (*c*) Three orders of magnitude
   - (*d*) Four orders of magnitude
   - (*e*) They are about equal.
2. The wavelength of a 5000 Hz sound wave having a speed of $5{\cdot}9 \times 10^3$ m/s in steel is about :
   - (*i*) 1 μm
   - (*ii*) 1 mm
   - (*iii*) 1 cm
   - (*iv*) 1 m
   - (*v*) 1 km
3. If a material is hard to compress, its velocity of sound is... ....
4. High frequency sound waves have ....wavelengths.
5. Loudness of a musical sound depends on...... ....
6. If the frequency of vibration of an object in air is increased, the characteristic of the resulting wave which much change is the
   - (*a*) amplitude
   - (*b*) speed
   - (*c*) wavelength
   - (*d*) intensity.

7. The lowest audible sound frequency for most people, in hertzs, is about
   (*i*) 6
   (*ii*) 20
   (*iii*) 60
   (*iv*) 256.
8. A sound wave in air has a frequency of 1000 Hz. Its period is..................
9. If the speed of a sound wave in air is 350 m/s and its frequency is 700 Hz, the wavelength is..................
10. The sound waves of high frequency are called........... .....and the sound waves of low frequency are called..................
11. When a body is maintained in a state of vibration by a periodic force of time-period equal to its own free period, the resulting phenomenon is known as
    (*i*) Interference
    (*ii*) an echo
    (*iii*) resonance
    (*iv*) polarization.
12. The note produced by the simplest mode of vibration is known as..................note and other notes of multiple frequencies are known as..................
13. Velocity of a sound wave=wavelength × ....
14. When a body vibrates with its natural frequency, it is said to execute.................. vibrations.
15. The velocity of sound in water is..................than the velocity of sound in iron.
16. The pitch of sound is determined by the..................of the vibrating body which gives out the sound.
17. ....is that characteristic of a musical sound which distinguishes between two sounds having the same loudness & pitch and it depends upon the presence of........... ....
18. Velocity of sound in air at 0°C is..................m/s.

[B] Very Short Answer-Type Questions

1. What is the source of sound ?
2. A tuning fork vibrating in air sets the molecules in the air in motion. How does the frequency of vibration of these molecules compare with the frequency of the tuning fork ?
3. How are frequency and time period of a sound wave related to each other ?
4. What kind of a wave is sound ?
5. If the two tuning forks are in resonance, what is true of their natural frequencies ?
6. How does the velocity of sound in air depend upon its temperature ?
7. How does the velocity of sound in air depend upon pressure ?
8. How does the velocity of sound in air depend upon humidity of air ?
9. Can a sound wave travel through vacuum ?

10. Name three sources of sound.
11. What is the speed of sound in air at 0°C ?
12. What is the speed of sound in water at room temperature ?
13. What is the speed of sound in iron ?
14. Can astronauts, on the surface of moon, converse with each other as on earth ?
15. Name the three tiny bones in the middle ear.
16. Name three main parts of the ear.
17. What are the next two harmonics of a vibrating string whose fundamental frequency is 256 Hz ? [**Hints** : 512 Hz & 768 Hz] [*A.I.S S. 1987*]

[C] Short Answer Type and Essay Type Questions

1. Would you expect a sound heard under water to have the same frequency as when heard in air if the sources vibrated identically ? Explain.
2. Describe clearly why a bell ringing inside a vacuum chamber cannot be heard on the outside.
3. When a deep-voiced man inhales hydrogen and then speaks, his voice sounds high-pitched. Why ?
4. It has been claimed that a certain singer could shatter a glass goblet by singing a particular note. Could this be true ? Explain.
5. A siren can be made by drilling equally spaced holes on a circle concentric to the axis of a solid metal plate or disk. When the disc is rotated while a jet of air is blowing against it near the holes, a siren like tone is given off. Explain how this gives the sensation of sound to the ear, and state what factors influence the pitch and quality of the tone.
6. (*a*) In a travelling soundwave are there any particles which are always at rest as the wave passes through ?

   (*b*) Are there any particles which are sometimes at rest ? Indicate which particles, and for how long they remain at rest.
7. Perhaps you have experienced the fact that some people have a harder time than others in carrying an ice-cube tray filled almost to the top with water without spilling the water. If we presume that all the people involved exercise equal care to avoid spilling the water, what might be a reasonable physical explanation of the different results ?
8. What are the main characteristics of sound waves ? Discuss them.
9. Explain the working of human ear with the help of a diagram.
10. A tuning fork and a violin produce sound of the same frequency. How can these be still distinguished ?
11. What is resonance ? How will you demonstrate the phenomenon of resonance ? [*A.I.S.S. 1987*]
12. How are sounds produced ?
13. Distinguish between intensity and loudness.
14. Distinguish between frequency and pitch.
15. How do the vibrations of the source of a musical tone differ from the vibrations of the source of a noise ?
16. What is the range of audio frequencies ? What name is applied to sound vibrations (*i*) below the audio-range ; (*ii*) above the audio-range ?

17. Why does a tuning fork sound louder when its stem is pressed against a table top ?

18. What conditions are necessary to produce resonance ?

19. The human ear is said to be a very sensitive instrument. Give reason to support this.

20. A person listening near one end of a long iron pipe hears two distinct sounds when the other end is struck with a hammer. Explain this and show why the two distinct sounds are not heard at precisely the same time.

21. Why is it difficult to hear a person speaking in the open air ? Why is he heard distinctly when he uses a hollow cone with the apex at his mouth ?

22. In the track events at athletic meetings should the time keepers start their watches with the flash of the pistol or with its sound ? Explain your answer.

23. The sound of soldiers marching can be heard by placing the ear on the ground, whereas it cannot be heard if the ear is at a little distance from the ground. Explain.

24. Show how the following factors affect the speed of sound in air

    (*a*) the direction of the wind
    (*b*) the presence of water-vapour in the air
    (*c*) temperature
    (*d*) change in pressure

25. State the three characteristics of musical sound and state on what each of them depends.

26. When you stand outside a room why are you able to tell whether the sound produced inside the room is that of a piano or that of a violin ?

27. A sound of high pitch is heard when the teeth of a circular saw meet the wood, but the pitch is reduced as the saw cuts through it ? Explain.

28. Will a sitar note sound the same in the cold season as in the hot season ? Explain.

29. Why does a violinist coming from outside have to retune his violin on entering an air-conditioned (*i.e.*, a very cold) room ?

30. On what does the pitch of the note given by a vibrating column of air depend ?

31. What is resonance ? Why do windows sometimes rattle when the low notes of a pipe are sounded ? Do you think windows could be broken in such a manner ?

32. Why are marching soldiers commanded to break step when they are crossing a long bridge ?

33. Describe briefly how you can demonstrate resonance in a vibrating air column.

34. What property or characteristic of a note is affected by the width of a pipe ? Is it the pitch, the loudness or the quality ? Explain.

35. (*a*) Define : Free vibrations ; Forced vibrations and Resonant vibrations (or sympathetic vibrations). Give an example of each.

    (*b*) How do we find the velocity of sound in air using resonance tube apparatus ?

36. The steam of the railway engine is seen first and the whistle is heard a little later. Why ?

37. During a thunderstorm one sees the lightning much before one hears the thunder, though both lightning and thunder occur simultaneously. Explain.

38. Hold a vibrating tumbler close to the ear. You will hear a clear humming sound. Why ?

PROBLEMS

1. The velocity of sound in seawater is 1531 m/s. Find the wavelength in seawater of a sound wave whose frequency is 256 Hz. [**Ans**. 5·98 m]

2. A tuning fork vibrating at 300 Hz is placed in a tank of water. (*a*) Find the frequency and wavelength of the sound waves in the water. (*b*) Find the frequency and wavelength of the sound waves produced in the air above the tank by the vibrations of the water surface. The velocity of sound is 1498 m/s in water and 331 m/s in air. [**Ans**. (*a*) 300 Hz ; 4·99 m (*b*) 300 Hz ; 1·10 m]

3. The velocity of sound waves in air at sea level is 331 m/s. Find the wavelength in air of a sound wave whose frequency is 440 Hz. [**Ans**. 0·75 m]

4. A tuning fork vibrating at 600 Hz is immersed in a tank of water, and the resulting sound waves in the water are found to have a wavelength of 2·5 m. What is the velocity of sound in the water ? [**Ans**. 1500 m/s]

5. A tuning fork of frequency 512 Hz was sounded over a resonance tube which has its lower end immersed in water. Resonance was obtained when the length of the air column was 151 mm and 483 mm. Calculate the speed of sound in air. [**Ans**. 339·97 ms^{-1}]

6. Velocity of sound in air is 330 m/s. What will be the wavelength of sound of frequency (*i*) 20 Hz (*ii*) 20000 Hz (*iii*) 50000 Hz and (*iv*) 120000 Hz [**Ans**. (*i*) 16·5 m ; (*ii*) 1·65 cm (*iii*) 0·66 cm (*iv*) 0·275 cm]

7. A tuning fork of frequency 384 Hz sends a sound wave in the air column with a velocity of 350 m/s. What is the minimum length of the air column required to get the resonance ? [**Ans**. 0·23 m]

8. The measured time interval between our seeing the lightning and our hearing the thunder is 5 seconds. What is the distance of cloud from us ? Velocity of sound in air is 333·3 m/s. [**Ans**. 1·7 km]

9. Calculate the time taken by light to travel a distance of 100 km. Velocity of light is 3×10^8 m/s. [**Ans**. $3{\cdot}3 \times 10^{-4}$ s]

10. Calculate the length of a narrow tube closed at one end which will resonate with a tuning fork of frequency 510 Hz if the velocity of sound is 340 m/s. [**Ans**. 16·7 cm]

11. The length of a cylindrical glass tube whose one end is closed and flat is 30 cm. The velocity of sound in air is 330 m/s. What is the fundamental frequency of vibration of the air column ? [**Ans**. 275 Hz]

12. A man sets his watch by the noon whistle of a factory at a distance of 1 km. How many seconds is his watch slower than the time piece of the factory ? Velocity of sound in air = 322 m/s. [**Ans**. 3·01 s]

CHAPTER 5

Reflection of Light

5.1. INTRODUCTION

Light is radiation that can produce the sensation of sight. Light is a form of energy. The sun, the stars, electric light bulbs, fluorescent lights, sodium vapour and mercury vapour lamps and many other things emit light. Such luminous bodies act as sources of light. Highly polished surface sends back most of the light in a definite direction that falls on it while light is scattered by a rough surface. When light is absorbed by a black oil, the temperature of the oil rises. Special type of curved mirror gives enlarged image as well as diminished image while the plane mirror does not.

Let us find answers to such type of questions in this unit.

When you switch on your torchlight on a misty evening or you watch the light from a car head lamp you will notice that the beam of light that leaves your torch or the car headlamp is a straight one. This is enough to suggest that light travels in a straight line, *i.e.*, light has rectilinear propagation. To show that light travels in a straight line, take two pipes (metal or cardboard), one straight and the other bent as shown in Fig. 5.1 (*b*) and a candle flame.

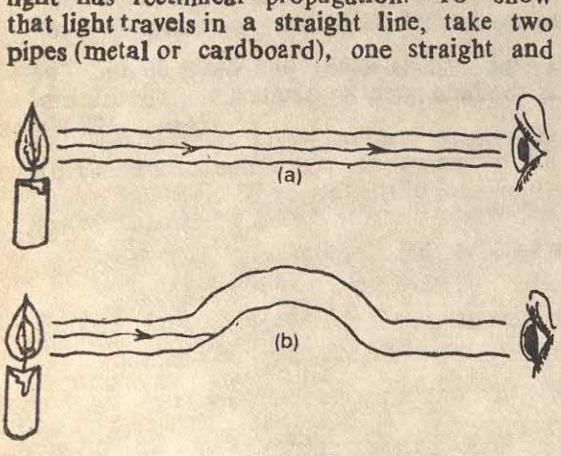


Fig. 5.1

Place the candle flame near one end of the straight pipe and look at it through the other end. Now replace the straight pipe with the bent one. What have you observed in both ?

In the first pipe you will see the light from the candle very clearly, while in the second pipe you will not see the light at all. This is because light can travel only in a straight line. It must be mentioned here that light can bend round small obstacles, sharp edges and corners, but this bending, called the **diffraction of light** cannot be detected by any simple experiment. Therefore, for all ordinary purposes the light may be assumed to travel in a straight line. Our inability to see things round the corner of obstacles, the casting of shadows by objects placed in the path of light are due to this property.

*How can light travelling in a straight line produce a picture ? Try the following experiment.

Take a cigarette tin or cardboard box, tissue paper, candle flame and a sharp pointed nail. Take off the cover of the cigarette tin or the cardboard box and replace it with ordinary tissue paper. Make a very tiny hole with a sharp nail at the centre of the bottom of the tin or the box. Now let it rest on its side and place the candle flame near the hole in a darkened room. Have a look at the tissue paper. What do you see ? In Fig. (5.2), XYNM is a tin, H is a hole and MN is the tissue paper screen.

You will see that clear inverted picture of the candle flame has been formed on the screen MN. Now proceed thus :

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*For extra knowledge only as it is not in the syllabus.

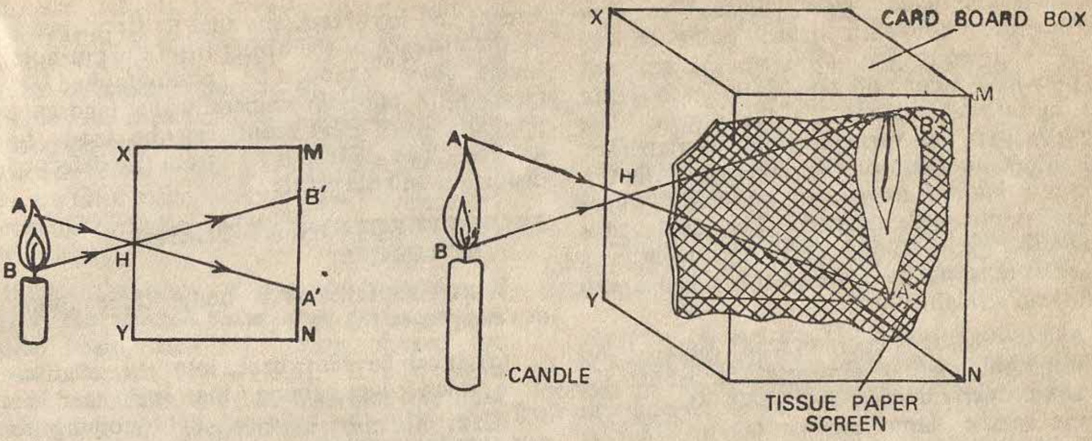


Fig. 5.2

(*a*) Move the candle flame farther and farther away from the hole and note the size and brightness of the image.

(*b*) Make the hole a bit larger and note what happens to the picture ?

Fig. (5.3) (*a*), (*b*) and (*c*) show how the picture of the candle flame is formed on the paper. Rays of light from the flame strike face XY. Most of them are stopped by the opaque tin, while the rest pass through the tiny hole. Since light has rectilinear propagation, a ray from the tip *A* of the flame would pass through the hole to *A'*, while a ray from *B* would pass through the hole to *B'*. *Thus on the paper screen there will appear an image of the flame upside down.* As the flame is moved away from the hole the image on the screen (MN) gets shorter and shorter and also less bright. Fig. (5.4) shows what happens when

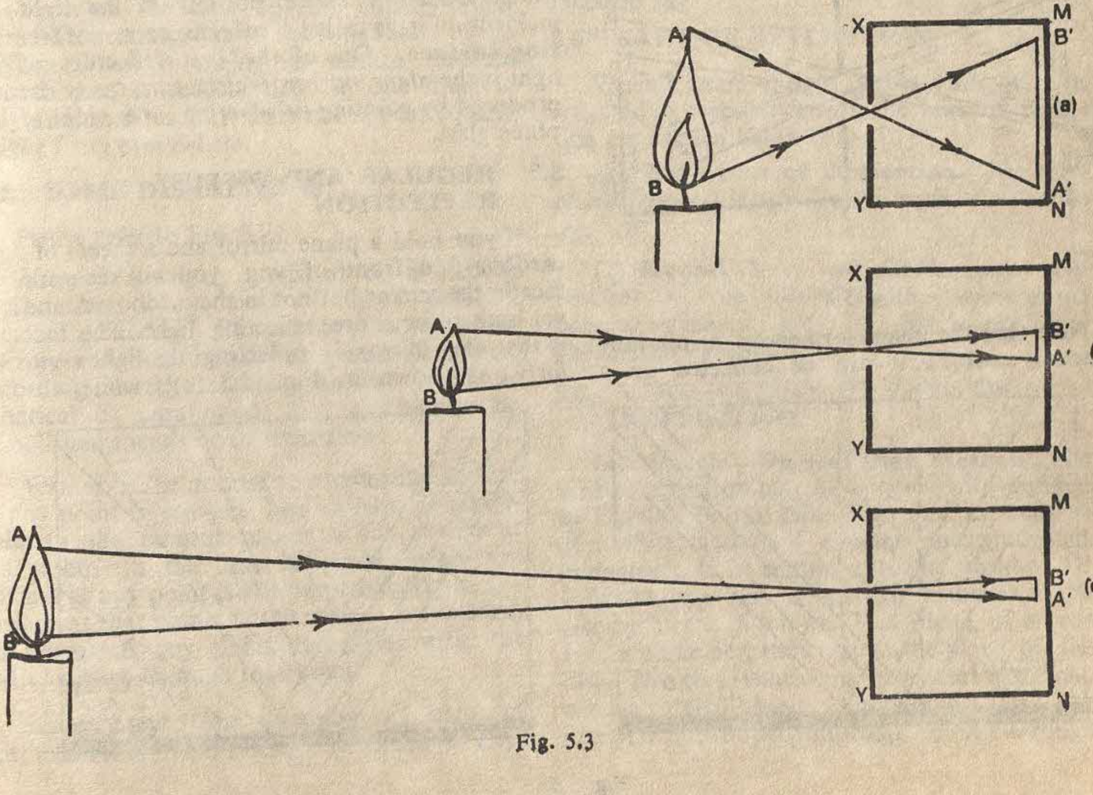


Fig. 5.3

the hole is made bigger. Instead of very narrow beams coming from each point on the flame as shown in Fig. (5.3) (*a*), (*b*) and (*c*), we now have a cone of rays from each point passing through the hole to the screen. The result is that the various cones overlap (*i.e.*, fall on one another) on the screen, and what is seen is a *blurred image i.e.*, an image whose outline is not well defined. The single rays drawn in Figs. (5.2) and (5.3) are really tiny cones of rays, but they are so tiny that we can call them straight lines.

If the tissue paper MN is replaced by photographic plate or film and the whole tin or box properly darkened, a good photograph of the candle flame can be taken. *That is why the arrangement is known as a* **pin-hole camera.** It has the advantage that the picture will be in focus, no matter where the object is, but the main difficulty is that a long exposure is required, since only a little light can pass through the tiny hole. As you probably know, long exposures are not good for the film.

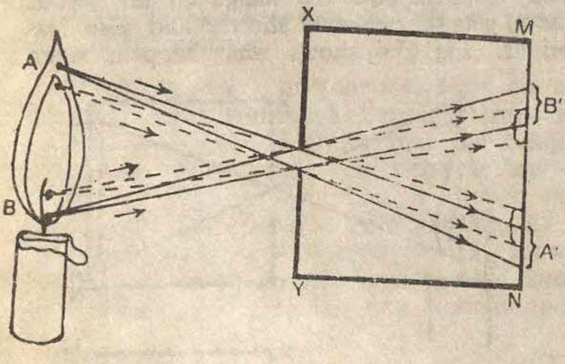


Fig. 5.4

Note that the image formed by a pin-hole camera is **real** (*i.e.* it can be collected on a screen) and **inverted**, and that its size depends on the distance of the object from the pin-hole. Living object cannot be photographed by means of a pin-hole camera while landscape photographs of great beauty can be made by its use. The picture is free from the defect of distortion and curvature.

5.2. REFLECTION AT PLANE SURFACES

When light falls on a body, three things can happen to the light :

(*a*) It can be sent back into the medium from which it was coming ; that is, it can be *reflected.* It is this reflected light coming to our eyes that enables us to see the body.

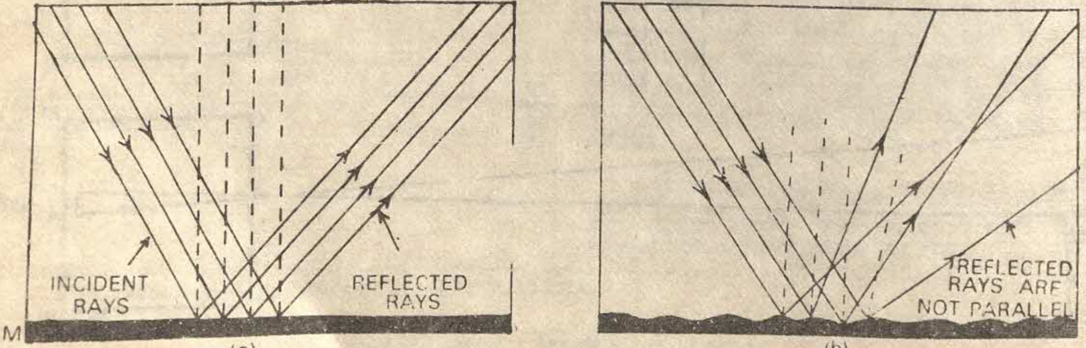
(*b*) In can be allowed to pass through the body ; that is, it can be *transmitted.* Only transparent and translucent bodies transmit different amounts of light.

(*c*) It can be *absorbed.* All bodies absorb light, but they absorb different amounts of it.

Every object reflects light, but the amount of light reflected is different for different objects. A highly polished or smooth surface, which reflects a major portion of the light incident on it, is called a **mirror** or a **reflecting surface**. One of the best reflectors of light is the *plane mirror* which can easily be produced by painting or silvering one side of plane glass.

5.3. REGULAR AND DIFFUSE REFLECTION

If you hold a plane mirror and a sheet of cardboard in front of you, you will see your face in the mirror but not in the cardboard, and yet both objects are reflecting light. The fact is that the mirror is reflecting the light *regularly* , as shown in Fig. [5.5 (*a*)], while the



(a) (b)

Fig. 5.5

cardboard reflects it *irregularly*, *i.e.*, *diffuses* or *scatters* it, as in [Fig. 5.5 (*b*)]. It is possibly with the former to form an image which appears behind the mirror, as you will see it later, but the cardboard cannot form an image. In the same way the rough surface of a table scatters light but when it is polished the tiny holes are filled with polish so that the table now reflects light regularly and you are able to see your face in it.

If a parallel beam of light falls on a smooth surface, the reflected beam also proceeds as a parallel beam, each ray having obeyed the laws of reflection [See Art 5.5]. If, however, a parallel beam falls on a rough surface like that of a blotting paper, regular reflection still takes place from each tiny element of the reflecting surface, but since these elements are not regularly arranged, the reflected rays go in various directions for any given direction of the incident rays, causing scattering or diffusion of light.

This diffused reflection is of great practical interest. In a cinema house the screen is rough and the light falling on it gets scattered in all directions enabling every person sitting inside the hall to see the picture on the screen. The snow on the hills appears equally bright from all directions due to the roughness of its surface. When it melts, its surface become smooth and it reflects light in one direction only and, as a result, it does not appear equally bright from everywhere.

5.4. SOME DEFINITIONS.

Please refer to Fig. 5.7

Mirror : A highly polished or a smooth surface from which most of light is reflected is called a **mirror**. The mirror is called *plane mirror*, *spherical mirror* or *parabolic mirror*, according as the reflecting surface is plane, spherical or paraboloid. The mirrors may be of polished metals or silvered glass.

Normal : The normal to a reflecting surface at any point is straight line drawn perpendicular to the tangent plane to the surface at that point. In the case of plane surface, the normal at any point is the perpendicular to the surface at that point. If the surface is spherical, the normal at any point coincides with the radius drawn through that point.

Ray of Light : The direction of path of light emanating from a source is called a **ray**. Rays are represented with straight lines with arrows marked on them.

Incident Ray : The ray coming to the reflecting surface is called the incident ray.

Reflected Ray : The ray going away from the reflecting surface after suffering reflection is called the reflected ray.

Point of Incidence : The point at which the ray strikes the surface is called the point of incidence.

Angle of Incidence : The angle of incidence is the angle between the incident ray and the normal to the reflecting surface at the point of incidence.

Angle of Reflection : The angle of reflection is the angle between the reflected ray and the normal to the reflecting surface at the point of reflection which coincides with the point of incidence.

Plane of Incidence : The plane of incidence is the plane containing the normal and the incident ray.

Plane of Reflection : The plane of reflection is the plane containing the normal and the reflected ray.

5.5. LAWS OF REFLECTION.

When a beam of light strikes a mirror it is reflected in accordance with the laws of reflection enunciated below (Fig. 5.7].

(1) **First Law of Reflection.** *The angle of incidence* (*i*) *is equal to the angle of reflection* (*r*).

(2) **Second Law of Reflection**. *The incident ray, the normal to the surface at the point of incidence, and the reflected ray lie in one and the same plane.*

5.6. VERIFICATION OF LAWS OF REFLECTION.

(*a*) **Hartle's Optical Disc Method** : The laws of reflection may be conveniently verified by Hartle's Optical Disc (Fig. 5.6). It consists of a white cardboard circular disc graduated in degrees. At its centre, a plane mirror *AB* is fixed along *XY*, a marked diameter of the disc by means of screws. The plane of mirror is in a plane perpendicular to the plane of the disc. The disc is held in a vertical plane and can be rotated about a horizontal axis. The line *MN* drawn perpendicular to *XY* through

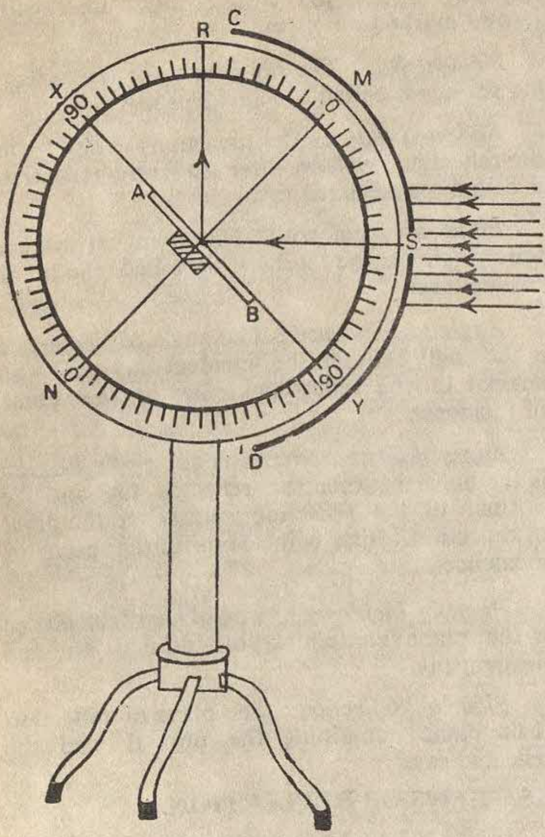


Fig. 5.6.

the centre of the disc shows the direction of the normal and coincides with the zero mark of the graduations. *CD* is a circular screen pierced with a slit *S* to admit light from an arc lamp.

Allow a beam of light to pass through the slit *S* so that it falls on the plane mirror *AB*. The paths of the incident and reflected rays can be seen and the angles they make with the normal *MN* read off. The angle of incidence may be varied by rotating the graduated disc. It will be found in all cases that the angles of incidence and reflection are equal proving the truth of the first law of reflection Since the incident ray, reflected ray and the normal *MN* lie in the plane of the cardboard, the second law of reflection stands verified.

(*b*) **Laboratory Method** : A simpler laboratory method of proving the laws of reflection is given below.

Fix a large sheet of white paper on a drawing board and mark a straight line *AB* on it (Fig 5.7). Support vertically a piece of plane mirror in the groove cut in a side of a block of wood *W*. *Place the plane mirror with its silvered surface on the line AB* Fix a pin *Q* near the front surface of the plan mirror. Fix another pin *P* at a distance c about 10 cm from *Q* in an oblique directior View the images of *P* and *Q* in the mirror an adjust the eye until the image of *Q* covers tha of *P*. Keeping the eye in this position fix two pins *R* and *S* at a distance of about 10 cm. apart so that these two pins are in line with the images of *P* and *Q*. The pins should be vertical. Remove the pins. Circle the pinpricks and draw lines *PQ* and *SR*. Let them meet at *C*. Draw *CN* perpendicular to *AB* at *C*. Measure $\angle PCN(=i)$, the angle of incidence and $\angle SCN(=r)$, the angle of reflection. It will be found that $i=r$. This proves the first law of reflection.

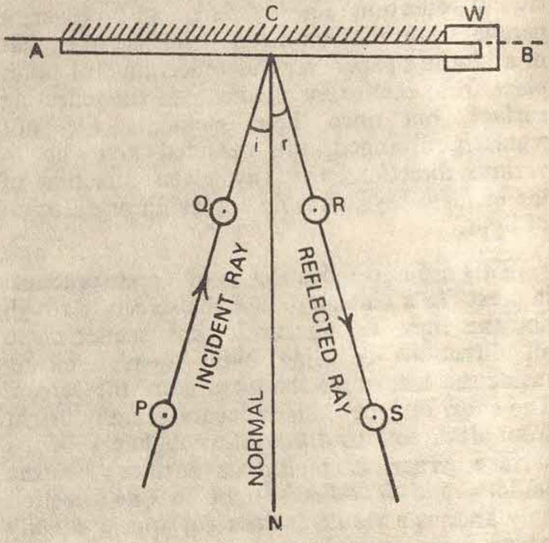


Fig. 5.7.

The join of the feet of the pins *P* and *Q* forms the incident ray and the join of the feet of the pins *R* and *S* forms the reflected ray. The feet of the pins lie in the plane of the paper. The normal *CN* also lies in the plane of the paper. Hence, the incident ray *PQ*, reflected ray *RS* and the normal *CN* lie in one and the same plane. This proves the second law of reflection.

5.7. IMAGE

If a pencil of rays diverging from a point, O, is caused by reflection (or refraction) to converge to or to appear to diverge from some other point, I, then I is called the image of the object O.

If the reflected (or refracted) rays of light actually pass through the second point I, the image is called the **real image**. If, on the other hand, they appear to diverge from the second point I, the image is called the **virtual image**.

In other words, an optical image of a point is the point of *intersection, real or virtual, of the reflected (or refracted) rays of light*. Hence in order to fix the position of an image of a point we have to trace the path of at least two rays by which it is formed.

A finite object is merely an assembly of points. Consequently, the image of a finite object is an assembly of image-points corresponding to the object points.

It may be pointed out here that the picture formed by a pin-hole camera is not at all an optical image as the path of light is not changed in any way in passing through the pin-hole and the rays do not intersect upon the screen.

5.8. FORMATION OF OPTICAL IMAGE BY A PLANE MIRROR

Let $M_1 M_2$ be a plane mirror placed at right angles to the plane of the paper (Fig. 5.8). Let L be a luminous point-object placed in the plane of the paper. Let LA be any ray incident on the plane mirror at A. The normal AN is drawn at A. Then the reflected ray AR will lie on the other side of the normal AN such that the angle of reflection RAN is equal to the angle of incidence LAN.

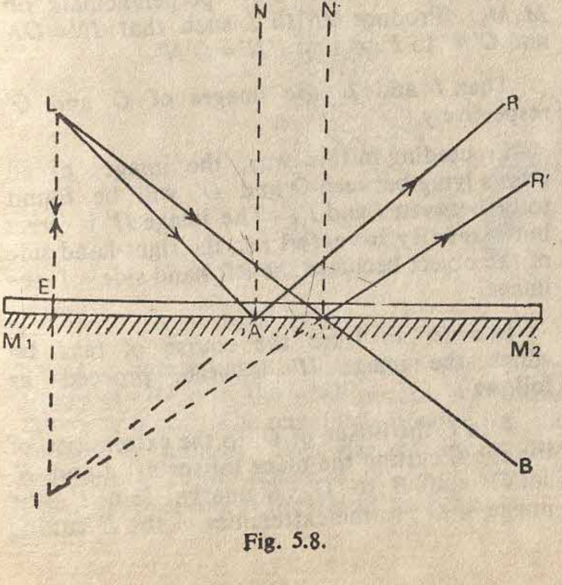


Fig. 5.8.

Draw LE perpendicular to $M_1 M_2$. This incident ray LE will be reflected back along EL. Produce EL and AR backwards so that these appear to diverge from I. Then I is the virtual image of L.

LI and NA are parallel as they are both perpendicular to the same line $M_1 M_2$. Hence,

$$\angle RAN = \angle AIE \qquad \ldots(1)$$

[being corresponding angles]

But $\angle RAN = \angle LAN$ [$\because$ Angle of reflection = Angle of incidence]

$$= \angle ALE \qquad \ldots(2)$$

[$\because$ $\angle LAN$ and $\angle ALE$ are alternate angles]

$\therefore$ From *eqs.* (1) and (2), we have

$$\angle AIE = \angle ALE \qquad \ldots(3)$$

In Δs ALE and AIE,

$\because$ AE is common $\angle ALE = \angle AIE$ [*vide eq.* (3),

$\angle AEL = 90° = \angle AEI$ [$\because$ $LE \perp M_1M_2$]

$\therefore$ Δs, are congruent.

Hence $LE = EI$ ...(4)

This result is independent of the point of incidence as shown by LA' and $A'R'$ rays. Hence we come to the conclusion that all the rays starting from L after reflection appear to diverge from I. In other words, I is the optical image of L.

Thus the image formed in a plane mirror lies as far behind it as the object lies in front of it.

The path of the ray $LA'\ B$ is turned through an angle given by

$$\angle R'A'B = 180° - \angle LA'R'$$

$$= 180° - 2 \times \angle LA'N'$$

$$= 180° - 2 \times \text{angle of incidence}$$

(C.T.M.)

This change in the direction of the path of light is called the **deviation**.

5.9. IMAGE FORMED BY PLANE MIRROR LIES AS FAR BEHIND IT AS THE OBJECT LIES IN FRONT OF IT. EXPERIMENTAL VERIFICATION

Take a plane mirror M_1M_2 supported in a groove cut in a side of a block of wood W and place it, as in art. 5.7, with its silvered side on the line AB drawn on a large sheet of paper fixed on a drawing board. Fix a pin O vertically in front of the plane mirror M_1M_2. View the image I of the pin O along PQ (Fig. 5.9) and fix vertically two pins P and Q so that they are in straight line with the image I. Similarly, view the image I along SR and fix vertically two pins R and S so that they are in straight line with the image I. The distance between P and Q or R and S should be about 10 cm. Remove the plane mirror and join the pricks of P and Q, and R and S. Let PQ and SR, when produced, meet at I which is the virtual image of O. Join OI. Let OI cut AB at E. On measurement, it will be found that $IE=OE$.

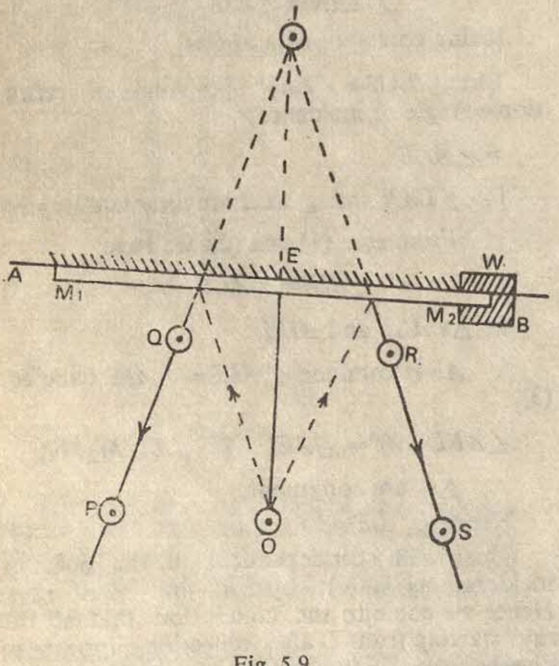


Fig. 5.9

Thus it proves that the image formed in a plane mirror lies as far behind it as it lies in front of it.

5.10. REFLECTION OF A CONVERGENT PENCIL BY A PLANE MIRROR

Let a convergent pencil of light, KL, be incident on the plane mirror M_1M_2 at AB (Fig. 5.10). If the plane mirror M_1M_2 had been absent, the pencil would have converged to a point O. Due to the presence of the plane mirror M_1M_2, the rays after reflection intersect at I such that $IC=OC$.

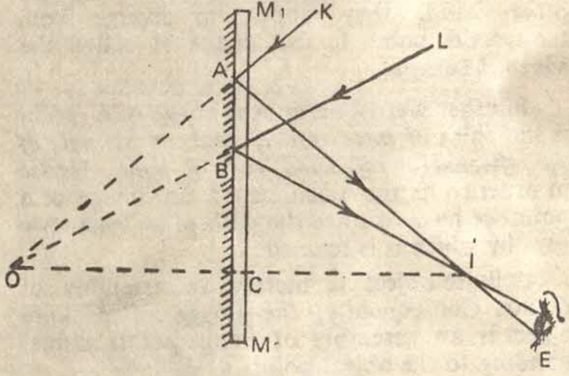


Fig. 5.10

When the eye is placed at E, it sees real image I. Notice that it is only in the case of a convergent pencil that a real image is formed in a plane mirror. In all other cases the plane mirror always gives a virtual image.

5.11. IMAGE OF A FINITE OBJECT IN A PLANE MIRROR

Let a finite object OO' be placed in front of a plane mirror M_1M_2 [Fig. 5.11(*b*)]. From O and O' draw ON and $O'N'$ perpendiculars on M_1M_2. Produce ON to I such that $IN=ON$ and $O'N'$ to I' so that $I'N'=O'N'$.

Then I and I' are images of O and O' respectively.

Proceeding in this way, the images of all points lying between O and O' will be found to lie between I and I'. The image II' is *erect* but **laterally inverted** *i.e.*, the right-hand side of the object becomes the left hand side of the image.

In order to trace the course of rays by which the image II' is seen, proceed as follows :

Join I, the image of O, to the extremities of the eye E cutting the plane mirror at A and B. Join A and B to O. Similarly, Join I', the image of O', to the extremities of the E cutting the plane mirror at A' and B'. Join A' and B' to O'. It is clear from the Fig. 5.11(b) that I' is seen by the cone of rays contained between OAE and OBE whereas I' is seen by the cone of rays contained between $O'A'E'$ and $O'B'E$.

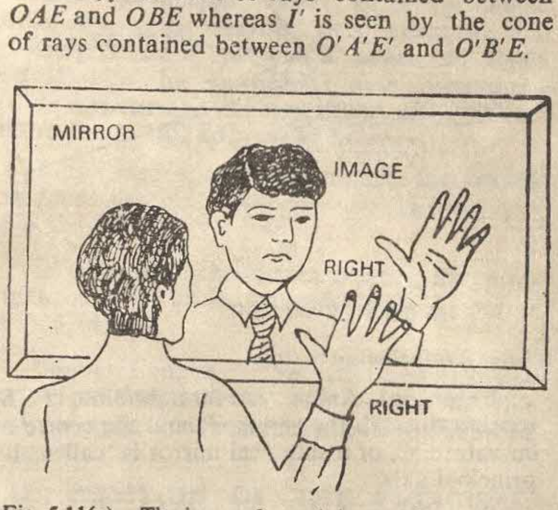


Fig. 5.11(a). The image formed by a plane mirror is reversed right and left. Observe that the image of the right hand has the symmetry of a left hand.

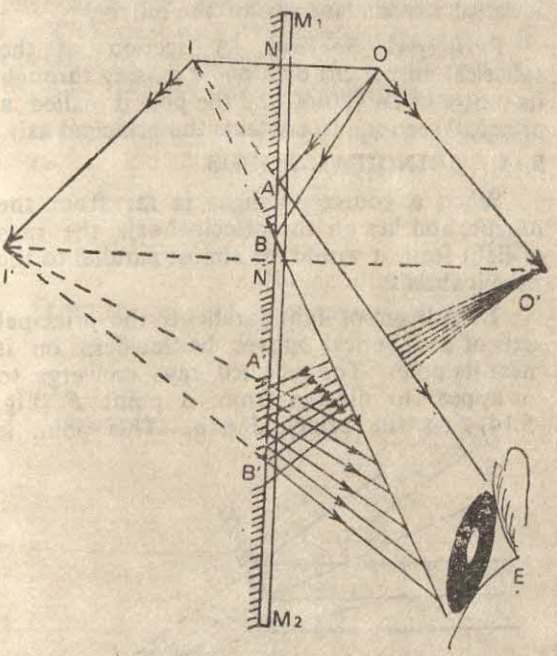


Fig. 5.11(b)

It is interesting to note that to see the image of OO' only the small portion AB' of the mirror is used. The remaining portion of the mirror is useless. The size of the mirror required to see the image of an object depends upon the position of the object and the eye.

An other point which may be borne in mind is that to see the image of an object, it need not be directly in front of the plane mirror.

5.12. ROTATION OF A PLANE MIRROR

Let the mirror M_1M_2 be rotated through an angle θ when AO be the incident ray of light. The direction of the reflected beam depends upon the position of the mirror. Hence, if this be changed, the direction of the reflected beam will also change. In Fig. 5.12 the angle through which the reflected ray of light gets rotated is $\angle B_1OB_2$.

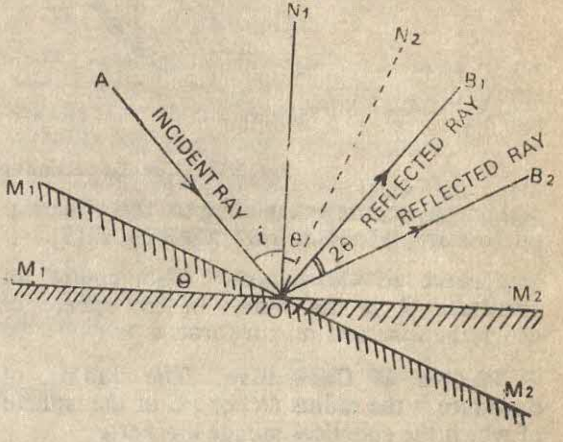


Fig. 5.12

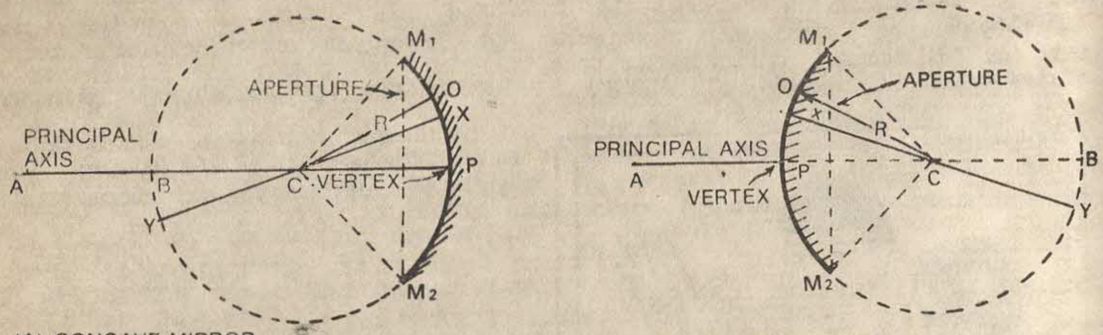
$$\text{Now } \angle B_1OB_2 = \angle N_2OB_2 - \angle N_2OB_1$$
$$= \angle AON_2 - \angle N_2OB_1$$
$$= [\angle AON_1 + \angle N_1ON_2] - [\angle N_1OB_1 - \angle N_1ON_2]$$
$$= \angle AON_1 + \angle\theta - \angle N_1OB_1 + \angle\theta$$
$$= \angle AON_1 + \angle\theta - \angle AON_1 + \angle\theta$$
$$= 2\angle\theta$$

Hence for a fixed incident ray, when a mirror rotates through a certain angle, the reflected ray rotates through twice that angle.

Sextant is an optical instrument which is based on this principle.

5.13. SPHERICAL MIRRORS

A spherical mirror is a part of a hollow sphere or a spherical surface whose one side is silvered and other side is polished (Fig. 5.13). It is either **concave**, or **convex**, according as the reflecting surface is towards, or away from, the centre of the sphere of which it forms a part (See Fig. 5.14). Before proceeding further,



(A) CONCAVE MIRROR

(B) CONVEX MIRROR

Fig. 5.13. Circular Sections of spheres form spherical mirrors.

certain physical terms relating to the spherical mirrors are defined below. (See Fig. 5.13).

Centre of Curvature. The centre of curvature, *C*, is the centre of the sphere of which the spherical mirror forms a part.

Radius of Curvature. The radius of curvature is the radius *OC* or *PC* of the sphere of which the spherical mirror is a part.

Normal. A radius drawn through a point on the spherical mirror is the normal to the mirror at that point. *OC* is the normal at *O*.

Vertex or Pole. The mid-point, *P*, of the spherical mirror is called its pole or vertex

Linear Aperture. The diameter, M_1M_2, of the spherical mirror is called its linear aperture.

Angular Aperture. The angle M_1CM_2 subtended by the diameter of a spherical mirror at its centre of curvature is called its angular aperture.

Principal Axis. The straight line, *PCB*, passing through the vertex, *P*, and the centre of curvature, *C*, of a spherical mirror is called its principal axis.

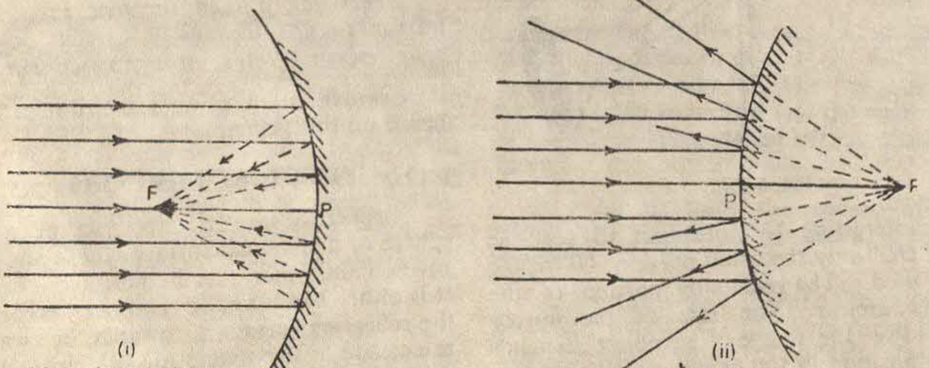
Secondary Axis. Any straight line, *XY*, other than the principal axis, passing through *C*, the centre of curvature of a spherical mirror, is called a secondary axis of the mirror.

Principal Section. A section of the spherical mirror cut by a plane passing through its centre of curvature and the pole is called a principal section It contains the principal axis.

5.14. PRINCIPAL FOCUS

When a source of light is far from the mirror, and lies on the principal axis the rays of light from it would be almost parallel to the principal axis.

Let a beam of light parallel to the principal axis of a spherical mirror be incident on it near its pole. The reflected rays converge to or appear to diverge from, a point *F* (Fig. 5.14) on the principal axis. This point is



(i) CONCAVE MIRROR

(ii) CONVEX MIRROR

Fig. 5.14

called **principal focus** of the spherical mirror. Thus the principal focus of a spherical mirror may be defined as follows :

The principal focus of a spherical mirror may be defined as a point on its principal axis where a beam of light parallel to the principal axis converges to or appears to diverge from after reflection from the spherical mirror.

In the case of converge mirror, the principal focus lies on its principal axis in *front of it* [Fig. 5.14 (*i*)].

In the case of the convex mirror, the principal focus lies on its principal axis *behind it* [Fig. 5.14 (*ii*)].

Focal Length. The distance of the principal focus from the vertex or the pole of spherical mirror is called its focal length.

5.15. POSITION OF THE PRINCIPAL FOCUS

Let OM_1 be a ray of light incident on a spherical mirror, say, a concave mirror M_1M_2 (Fig. 5.15) near its pole in such a way that it is parallel to the principal axis of the mirror. It will be reflected along M_1F such that

angle of reflection $= r = i =$ angle of incidence

i.e. $\angle FM_1C = \angle OM_1C$

$\therefore$ OM_1 is parallel to CP,

$\therefore$ $\angle M_1CF = \angle OM_1C$ ...(2)

[Being alternate angles]

From the *eqns.* (1) and (2), we get

$$\angle FM_1C = \angle M_1CF$$

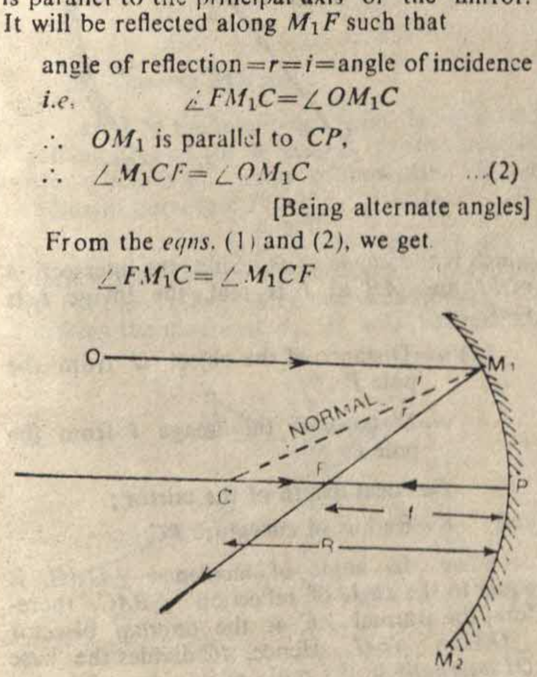


Fig. 5.15

Which shows that $\triangle\, M_1CF$ is isosceles and hence

$$M_1F = FC$$

Since the ray OM_1 is incident M_1 close to P, the pole of the spherical mirror, M_1F is *approximately* equal to PF. Hence

$$\left.\begin{aligned} & PF = PC \\ \text{or} \quad & PF = \tfrac{1}{2}PC \\ \text{or} \quad & f = \tfrac{1}{2}R \end{aligned}\right\} \quad ...(3)$$

The *eqn*. (3) shows that

(i) The focus, F, lies midway between P, the pole or vertex, and C, the centre of curvature, and (ii) The focal length, PF, of a sperical mirror is half of its radius of curvature, PC.

5.16. ASSUMPTIONS EMPLOYED IN THE FORMATION OF IMAGES BY SPHERICAL MIRRORS

While dealing with the formation of images in a spherical mirror, the following assumptions will be made :

(*i*) *The aperture of the spherical mirror is small.*

(*ii*) *The object lies on the principal axis.*

(*iii*) *The light is not incident very obliquely, i.e., the incident ray is nearly parallel to the principal axis of the spherical mirror.*

(*iv*) *The incident ray is not very divergent.*

5.17. NEW SIGN CONVENTIONS USED IN PROVING THE MIRROR FORMULA

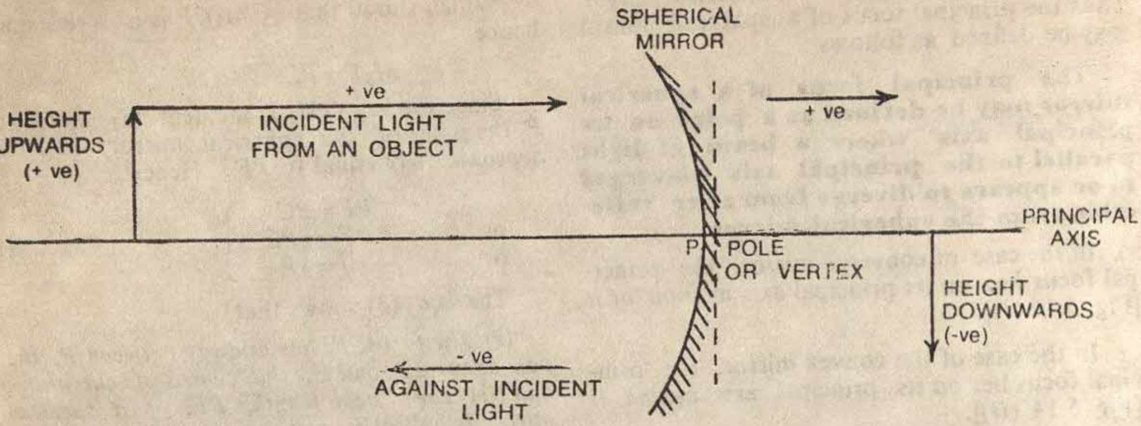
A number of sign conventions are used in deducing the spherical mirror formula. In this book we will use the new sign conventions which are given below : [Fig. 5.15 (*a*)].

(*i*) The light rays will be taken to be travelling from **left to right**

(*ii*) All distances are measured from the pole (or vertex) of a spherical mirror.

(*iii*) Distances measured in the same direction as that of the incident light are taken as **positive** and the distances measured against the direction of incident light are taken as **negative**.

(*iv*) Heights or distances measured upwards and perpendicular to the principal axis are considered **positive** whereas heights



(NEW SIGN CONVENTIONS)

Fig. [5.15 (*a*)]

or distances measured downwards and perpendicular to the principal axis are considered **negative.**

(*v*) The distances of the object image and the principal focus from the pole of a spherical mirror are denoted by letters u, v and f respectively.

According to the above mentioned new sign conventions :

(*a*) *Radius of curvature* and *focal length* of **a convex mirror** is taken as **positive** while the radius of curvature and focal length of a *concave mirror* is taken as **negative.**

(*b*) The distance of an *object* (v) is always **negative.**

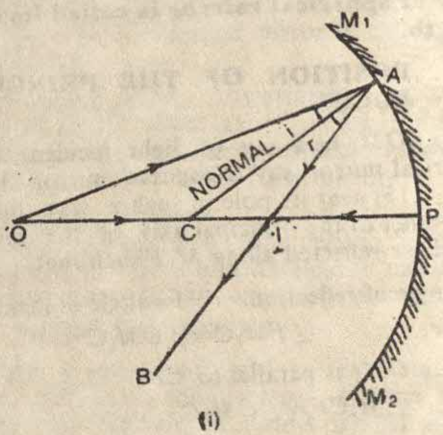
(*c*) The distance of a *real image* (v) is **negative** while that of *virtual* image (v) is **positive.**

5.18. SPHERICAL MIRROR FORMULA

(i) Concave Mirror :

Let O be a luminious point lying on the principal axis of a concave mirror M_1M_2 whose pole is P, centre of curvature C, and radius of curvature PC [Fig. 5.16 (*i*)].

The ray OP falls on the concave mirror normally and hence after reflection it retraces its path along PO. Consider another ray OA striking the mirror at A. It will be reflected along AB so that OA and AB are equally inclined to the normal AC and lie on its opposite sides making angle of incidence, $\angle OAC$, equal to the angle of reflection $\angle BAC$. The two reflected rays PO and AB intersect at I which is the image of O. Since the intersection of PO and AB at I is real, the image I is *real.*



(i)

[Fig. 5.16

Let u=Distance of the object O from the pole P ;

v=Distance of the image I from the pole P,

f=Focal length of the mirror ;

and R=Radius of curvature PC.

Since the angle of incidence $\angle OAC$, is equal to the angle of reflection $\angle BAC$, therefore, the normal AC is the *internal* bisector $\angle OAI$ in $\triangle OAI$. Hence, AC divides the base *OI internally* in the radio of its sides. Thus

$$\frac{CO}{CI}=\frac{OA}{AI} \qquad ...(1)$$

Assuming the aperture of the mirror to be small we have

$$\left.\begin{aligned} OA&=OP=-u\\ AI&=PI=-v\\ PC&=-R \end{aligned}\right\}\text{(sign conventions)}$$

$$\begin{aligned}\text{Also,}\quad CI&=PC-PI\\ &=-R-(-v)\\ &=v-R\end{aligned}$$

$$\begin{aligned}\text{and}\quad CA&=PO-PC\\ &=-u-(-R)\\ &=R-u\end{aligned}$$

Hence equal (i) becomes

$$\frac{R-u}{v-R}=\frac{-u}{-v}=\frac{u}{v}$$

or $vR-uv=uv-uR$

or $vR+uR=2uv$

Dividing both sides by uvR, we get

$$\frac{1}{u}+\frac{1}{v}=\frac{2}{R}$$

But $R=2f$ (proved earlier)

$$\therefore\quad \boxed{\frac{1}{u}+\frac{1}{v}=\frac{1}{f}}\quad \text{...(2) (C.T.M.)}$$

(*ii*) **Convex Mirror** :

Let O be the luminous point lying on the principal axis of a convex mirror M_1 M_2 whose pole is P, centre of curvature C, and radius of curvature PC [Fig. 5.16 (*ii*)].

The ray OP falls on the convex mirror normally and hence after reflection it retraces its path along PO. Consider another ray OA striking the mirror at A. It will be reflected along AB so that OA and AB are equally inclined to the normal CAN and lie on its opposite side making angle of incidence $\angle OAN$ equal to the angle of reflection $\angle BAN$. The two reflected rays PO and AB *appear* to intersect at I on the principal axis which is the image of O Since the intersection of PO and AB at I is virtual, so the image I is *virtual*.

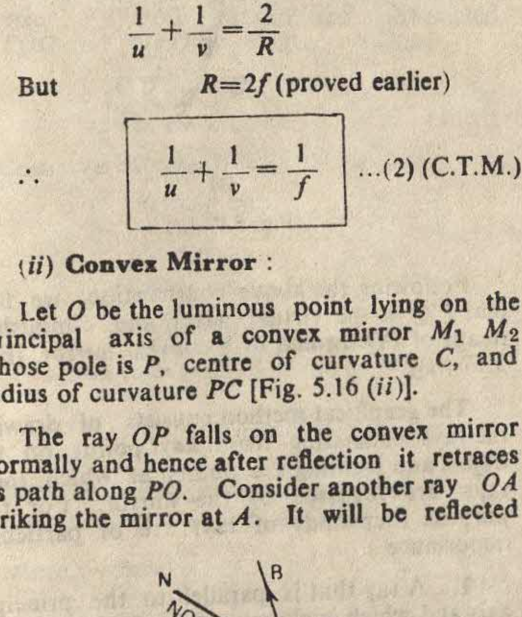


Fig. 5.16 (*ii*)

Let u = Distance of the object O from the pole P,

v = Distance of the image I from the pole P,

f = Focal length of the mirror,

and R = Radius of curvature PC.

Since the angle of incidence $\angle OAN$ is equal to the angle of reflection $\angle BAN$, therefore, the normal CAN is the *external* bisector of $\angle BAO$ in ΔOAI. Hence CAN divides the base OI *externally* in the ratio of its sides. Thus

$$\frac{CO}{CI}=\frac{OA}{AI}\qquad\text{...(1)}$$

Assuming the aperture of the mirror to be small, we have

$$\left.\begin{aligned} OA&=OP=-u\\ AI&=PI=v\\ PC&=R \end{aligned}\right\}\text{(sign conventions)}$$

Also, $CO=PC+PO=R-u$

$$\begin{aligned}\text{and}\quad CI&=PC-PI\\ &=R-v\end{aligned}$$

Hence, equation (1) becomes

$$\frac{R-u}{R-v}=\frac{-u}{v}$$

or $vR-uv=-Ru+uv$

or $vR+uR=2uv$

Dividing both sides by uvR, we get

$$\frac{1}{u}+\frac{1}{v}=\frac{2}{R}$$

But $R=2f$ (proved)

$$\therefore\quad \boxed{\frac{1}{u}+\frac{1}{v}=\frac{1}{f}}\quad \text{......(2) [C.T.M.]}$$

From the above discussion it is clear that the relation

$$\frac{1}{u}+\frac{1}{v}=\frac{1}{f}$$

holds in the case of a concave mirror as well as convex mirror. While using the above formula, only the *known* quantities should be substituted with *proper* signs. The sign of the unknown quantity will occur in the final solution.

5.19. CONJUGATE FOCI

The points P and I connected by the relation

$$\frac{1}{u}+\frac{1}{v}=\frac{1}{f}$$

are said to be the **conjugate foci.** It means that positions of the object and the image are interchangeable. If the object is placed at I, its image will be formed at O and *vice versa*.

5.20. GRAPHICAL METHOD FOR LOCATING IMAGE

Let PQ be a small object placed on the principal axis of a spherical concave mirror M_1M_2 [Fig. 5.17 (*i*)]. Since the object is an assembly of points, its image may be found as follows :

Consider a ray PA parallel to the principal axis. It strikes the spherical mirror at A. After suffering reflection, it passes through the focus F. Another ray PC passes through the centre of curvature of the concave mirror and as it strikes the mirror normally at B it retraces its steps along BCP. The reflected rays AF and BCP actually intersect each other at P' which is the *real* image of P. Another ray PO after reflection will travel along OP'. One may take another ray directed towards the focal point F which will be reflected *parallel* to the principal axis, again intersecting at P'. Similarly, the image of any other point of the object can be determined. Draw a perpendicular from P' on the principal axis to cut it at Q'. It is clear from the Fig. 5.17(*i*) that $P'Q'$ is the real inverted and diminished image of PQ, where $P'Q'$ has been drawn perpendicular to the principal axis since PQ is also perpendicular to the principal axis.

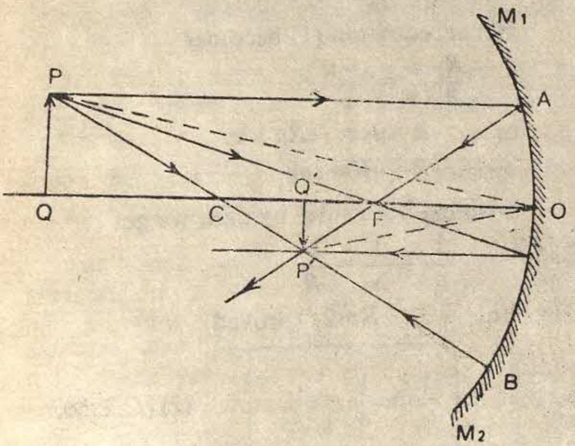
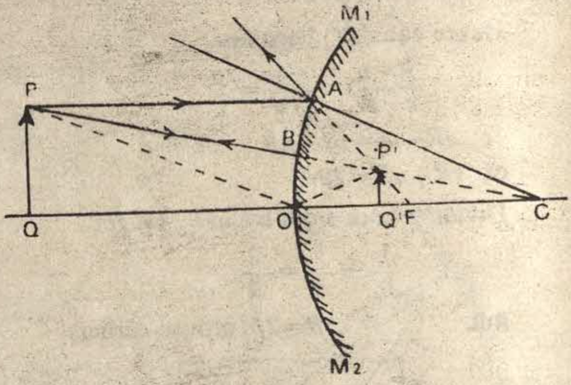


Fig. 5 17 (*i*)



(ii)

Fig. 5.17 (*ii*)

Following the above construction, we find that $P'Q'$ is the virtual, erect and diminished image of PQ formed by a convex mirror [Fig. 5.17 (*ii*)].

The graphical method consists of drawing the rays emanating from key points on the object and locating the points at which these rays are focussed by the mirror. For this purpose four kinds of rays are of particular importance :

1. A ray that is parallel to the principal axis and which is always reflected through the principal focus F of the mirror.

2. A ray that passes through the principal focus F first and which is then reflected parallel to the principal axis (the reverse of ray 1).

3. A ray which strikes the mirror at its vertex or pole (*i.e.*, the point at which the principal axis intersects the mirror). Such a ray is always reflected in such a way that the angle of incidence with respect to the principal axis is equal to the angle of reflection.

4. A ray that passes through the centre of curvature and which is reflected back through the centre of curvature, since it strikes the mirror normal to its surface.

5.21. LINEAR MAGNIFICATION

The **linear magnification** may be defined as the ratio of the size of the image to the size of the object. Thus,

$$\text{Linear Magnification} = \frac{\text{Size of the image}}{\text{Size of the object}}$$

or $$m=\frac{I}{O}.$$

To determine the linear magnification produced by a spherical mirror let us consider the two right-angled triangles *PQO* and *P′Q′O* [Fig. 5.17 (*i*) and (*ii*)]. Since the angle of incidence, ∠*PQO*, is equal to the angle of reflection, ∠*P′OQ′*, therefore the right-angled △s *PQO* and *P′Q′O* are similar. Hence,

$$\frac{P'Q'}{PQ}=\frac{OQ'}{OQ} \qquad \ldots(1)$$

Concave Mirror [Fig. 5.17 (*i*)] :—

$$P'Q'=I$$
$$PQ=0$$
$$OQ'=-v$$
$$OQ=-u$$

∴ From equation (1), we have

$$\frac{I}{O}=\frac{-v}{-u}=\frac{v}{u}$$

Now using the sign convention, the magnification is **negative** for an inverted image.

Therefore, $-m=\frac{v}{u}$

∴ $$\boxed{\text{magnification } (m)=\frac{I}{O}=\frac{-v}{u}} \quad \ldots(2)$$

(C.T.M.)

The △s *OAF* and *P′Q′F* are also similar.

Hence,

$$\frac{P'Q'}{AO}=\frac{FQ'}{OF}$$

or $$\frac{P'Q'}{PQ}=\frac{FQ'}{OF} \quad [\because \; AO=PQ]$$

or $$\frac{-I}{O}=-\left(\frac{-v+f}{-f}\right)$$

or $$\boxed{m=\frac{I}{O}=\frac{f-v}{f}} \quad \ldots(3) \text{ (G.T.M.)}$$

From the spherical mirror formula

$$\frac{1}{u}+\frac{1}{v}=\frac{1}{f}$$

or $$\frac{1}{v}=\frac{1}{f}-\frac{1}{u}=\frac{u-f}{uf}$$

or $$v=\frac{uf}{u-f}$$

or $$\frac{v}{f}=\frac{u}{u-f}$$

Putting this value of $\frac{v}{f}$ in the eq. (3), we get

$$m=1-\frac{v}{f}$$
$$=1-\left(\frac{u}{u-f}\right)$$
$$=\frac{f}{f-u}$$

or $$\boxed{m=\frac{f}{f-u}} \quad \ldots(4) \text{ (C.T.M.)}$$

From equations (2), (3) and (4) we find that the linear magnification produced by a concave mirror is given by

$$m=-\frac{v}{u}=\frac{f-v}{f}=\frac{f}{f-u} \qquad \text{(C.T.M.)}$$

Convex Mirror [Fig. 5.17 (*ii*)]

$$P'Q'=I$$
$$PQ=O$$
$$OQ'=v$$
$$OQ==-u$$

∴ From equation (1), we have

$$\frac{I}{O}=\frac{v}{-u}$$

Using the sign convention, the magnification is *positive* for *an erect* image. Therefore,

$$m=\frac{I}{O}$$

or

$$\boxed{\text{magnification } (m)=\frac{I}{O}=-\frac{v}{u}}$$

...(5) (**C.T.M.**)

The Δs OAF and $P'Q'F$ are also similar. Hence

$$\frac{P'Q'}{AO}=\frac{FQ'}{OF}$$

or $$\frac{P'Q'}{PQ}=\frac{FQ'}{OF} \qquad (\because \; AO=PQ)$$

or $$\frac{I}{O}=\frac{f-v}{f}$$

or $$\boxed{m=\frac{f-v}{f}}$$

...(6) (**C.T.M.**)

From the spherical mirror formula

$$\frac{1}{u}+\frac{1}{v}=\frac{1}{f}$$

or $$\frac{1}{v}=\frac{1}{f}-\frac{1}{u}=\frac{u-f}{uf}$$

or $$v=\frac{uf}{u-f}$$

or $$\frac{v}{f}=\frac{u}{u-f}$$

Putting this value of $\frac{v}{f}$ in the eq. (6), we get

$$m=1-\frac{v}{f}$$

$$=1-\frac{u}{u-f}$$

$$=\frac{u-f-u}{u-f}$$

$$=\frac{-f}{u-f}$$

or $$\boxed{m=\frac{f}{f-u}}$$

...(7) (**C.T.M.**)

From equations (5), (6) and (7), we find that the linear magnification produced by a Convex Mirror is given by

$$m=-\frac{v}{u}=\frac{f-v}{f}=\frac{f}{f-u}$$

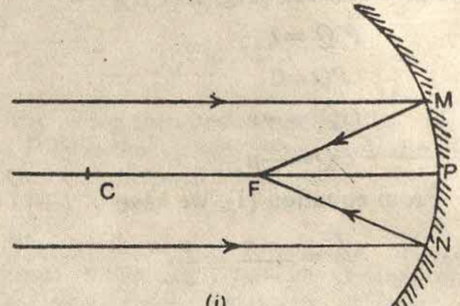
(**C.T.M.**)

The magnitude of m can be greater or less than unity depends upon the values of u and v. If it is greater than unity the image formed is enlarged otherwise it is diminished. If m is *positive*, the image formed is *erect*. If m is *negative* then the image is *inverted*.

5.22. NATURE, POSITION AND SIZE OF IMAGE FORMED BY A CONCAVE MIRROR

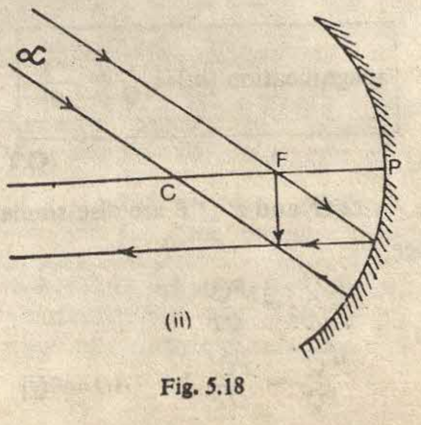
Let us start with the object at infinity and gradually bring it nearer to the mirror. The following cases arise :

(*i*) **When the object lies at infinity.** Here, the incident rays are all *parallel to each other*. Obviously then, *two cases arise, viz.,*



(*i*)

Fig. 5.18

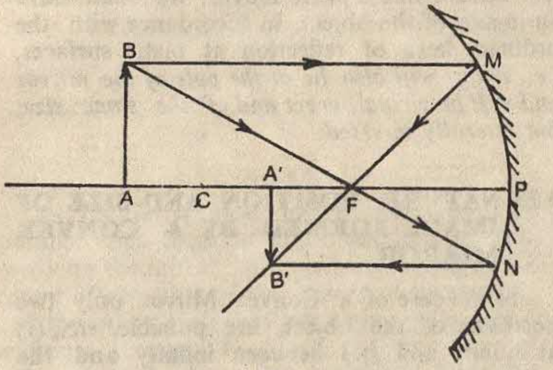


(ii)

Fig. 5.18

(a) when the rays are parallel to the principal axis, [Fig. 5.18 (i)], and (b), when they are not parallel to the principal axis, [Fig. 5.18 (ii)].

In either case, the rays after reflection at the mirror, converge to form a real, *inverted* and *extremely diminished image at the focus or focal plane.*



(iii)

Fig. 5.18

(*ii*) **When the object lies beyond the centre of curvature.** Let *AB* [Fig. 5.18 (*iii*)], be an object, placed beyond *C*, the *centre of curvature* to the mirror. Then, a ray from *B*, *parallel to the principal axis,* passes through the *focus F*, after reflection at the mirror, and another ray from *B*, passing through the *focus F*, after reflection at the mirror, gets reflected parallel to the axis, so that the two reflected rays meet at *B'*, which, is therefore, the image of *B*. From *B'* drop a perpendicular *B'A'* on to the axis, to meet it in *A'*, which is then the image of *A*. Thus, *A'B'* is the image of *AB*, and as is clear from the figure, *it is between the focus and the centre of curvature, and is real, inverted and diminished.*

(*iii*) **When the object lies at the centre of curvature.** Let the object *AB*, (Fig. 5.18 (*iv*)], lie at *C*, the *centre of curvature* of the mirror. Then, proceeding as in case (*ii*), *i.e.*, considering two incident rays from *B*, one *parallel to the axis*, and the other, passing through the *focus F*, we find that on reflection the former passes through *F*, and the latter becomes parallel to the axis, the two meeting to form an image of *B* at *B'*. Then, dropping *A'B'* perpendicular to the axis, we get the image *A'B'*, of the object *AB*, which *also lies at the centre of curvature C, is real and inverted* and *of the same size as the object.*

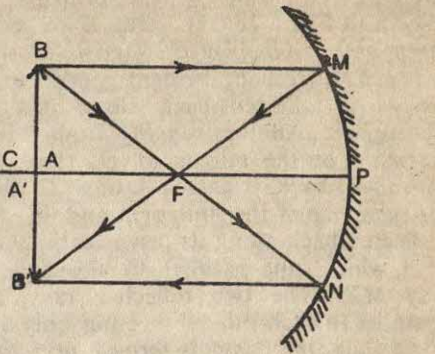
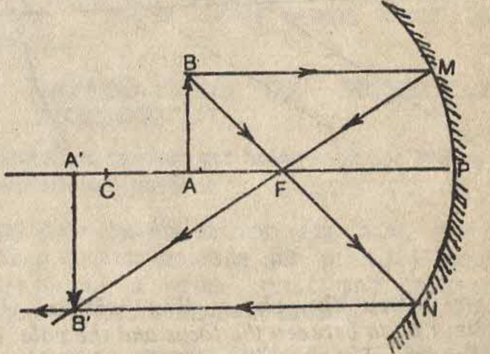


Fig. 5.18 (*iv*)

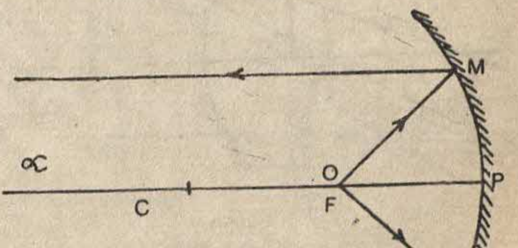
(*iv*) **When the object lies in between the centre of curvature and the focus.** Let the object *AB* [Fig. 5.18 (*v*)] be now placed between *C* and *F*. Then, proceeding exactly as in cases (*ii*) and (*iii*), we have its *real, inverted* and *magnified image A'B'*, formed *beyond C.*



(v)

Fig. 5.18

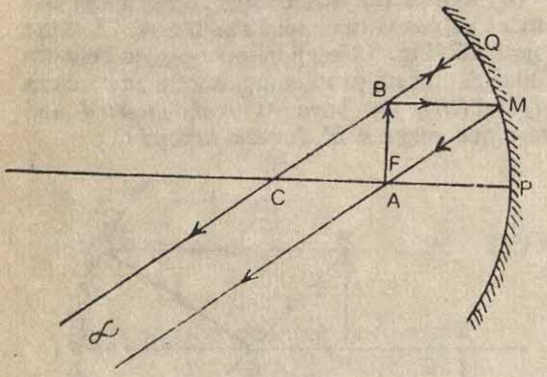
(*v*) **When the object lies at the focus.** Here, if we consider a *point object (O) at the focus* (*F*), rays from it, incident on the mirror



(vi)

Fig. 5.18

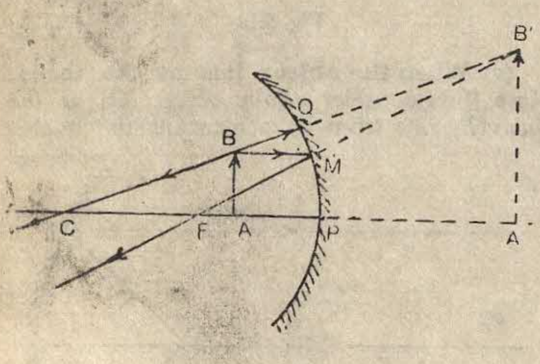
are rendered parallel to the principal axis, as shown in Fig. 5.18 (*vi*). But, if we consider a *finite object AB*, [Fig. 5.18 (*vii*)], at the focus, a ray *BM*, from *B*, incident parallel to the axis at *M* is reflected back along *MF*, passing through *F*. Another ray *BQ*, from *B* is incident *normally* on the mirror at *Q*. (for, on being produced back, it passes through *C*, the centre of *curvature* of the mirror), and is, therefore, reflected back along its own path, *i.e.*, along *QB*, which runs parallel to the first reflected ray *MF*. The two reflected rays are thus parallel to each other, meeting only at *infinity*. And thus, *the image is formed at infinity, and is real, inverted and highly magnified.*



(vii)

Fig. 5.18

(*iv*) When the object lies within the focus, *i.e., in between the focus and the pole of the mirror.* Let an object *AB*, [Fig. 5.18 (*viii*)], be placed on the axis of the mirror, between *F* and *P*, (*pole* of the mirror). Then, proceeding exactly as in case (*v*) above, we find that the two reflected rays *MF* and *QB appear to meet* at *B′*, when produced backwards, and thus we get a *virtual, magnified and erect image A′B′* of the object *AB*, *behind the mirror.*



(viii)

Fig. 5.18

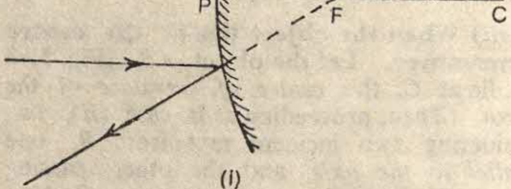
(*vii*) When the object lies at the pole of the mirror. If we have a small or a *point object* placed right on the *pole* of the concave mirror, then, since a small portion of it would just behave like a *plane* mirror, we shall have an image of the object, in accordance with the ordinary laws of reflection at plane surfaces, *i.e., image will also lie at the pole of the mirror and will be virtual, erect and of the same size, but laterally inverted.*

5.23 NATURE, POSITION AND SIZE OF IMAGE FORMED BY A CONVEX MIRROR

In the case of a Convex Mirror only two positions of the object, are possible, *viz.*, (*i*) at infinity and (*ii*) between infinity and the pole of the mirror.

(*i*) When the object lies at infinity.

Here the rays are incident on the convex mirror and parallel to each, other. Now, two cases arise, *viz.* (*i*) When the rays are also parallel to the principal axis [Fig. 5.19 (*i*)], and (*ii*). When they are not parallel to the principal axis [Fig. 5.19 (*ii*)].



(i)

Fig. 5.19.

In the former case the rays on reflection at the mirror, *appear to diverge* from the focus, *F*, thus giving a *virtual* and almost a *point-image* at the focus.

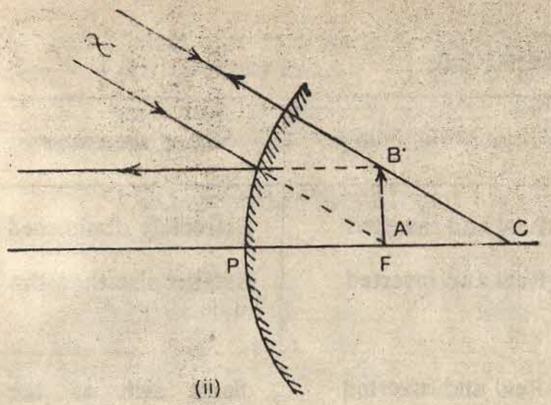


Fig. 5.19

In the latter case, let us consider two parallel rays from the object one incident *normally* on the mirror, (*i.e., passing through the centre of curvature of the mirror* if produced), and the other, such that on being produced it will pass through *F*. Then the first ray is reflected back along its own path, and the latter is rendered parallel to the axis, on reflection at the mirror, the two *appearing to meet* at *B'*, when produced backwards. On dropping a perpendicular, *B'A'*, from *B'*, on to the axis, we get *A'B'*, as the *virtual image* of the object *at the focal plane*.

Thus, in either case, the *image lies at the focus and is virtual, erect and extremely diminished.*

(*ii*) **When the object lies between infinity and the pole of the mirror.** Let an object *AB* be placed on the axis of the convex mirror, with *C*, as its *centre of curvature*, and *F*, its *focus* [Fig. 5.19 (*iii*)].

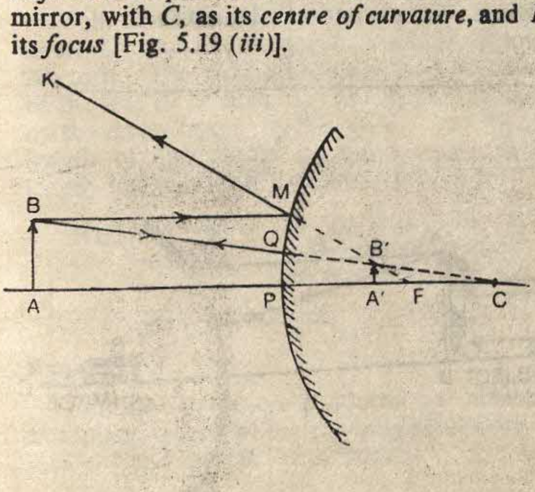


Fig. 5.19

Then, a ray *BM*, from *B*, and incident on the mirror at *M* in a direction *parallel to the axis*, is reflected along *MK*, such that, if produced backwards, it will pass through *F*. Another ray *BQ*, from *B*, (such that, if produced, it will pass through *C*), is incident *normally* on the mirror and is reflected back along its own path, so that the two reflected rays, *appear* to meet at *B'*, *behind the mirror*, giving us a *virtual* image *A'B'* of the object *AB*, between *F* and *P* the pole of the mirror.

Thus the image in this case *lies between the focus and the pole of the mirror, and is again virtual, erect and diminished.*

No other case is possible, *as both the focus and the centre of curvature of the mirror lie on the back side of the mirror.*

And since the object and image travel in opposite directions, the image moves from *F* towards *P* as the object moves from infinity towards *P* but is *always virtual, erect and diminished.*

5.24 APPLICATIONS OF SPHERICAL MIRRORS :

Spherical mirrors are being used for following mentioned purpose :

(*i*) As a shaving mirror (Fig. 5.20) When we keep the face closer to the principal focus of the mirror, a virtual, erect and enlarged image is formed behind the mirror.

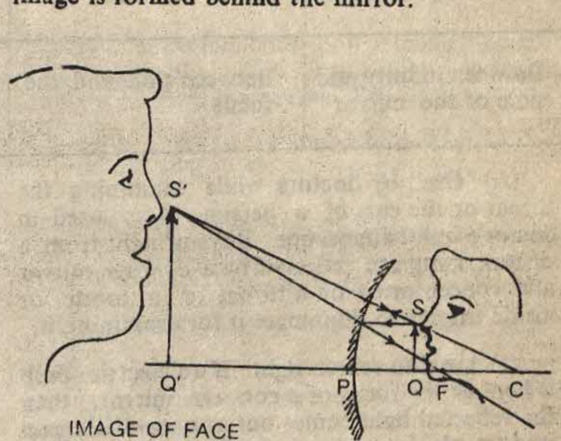


Fig. 5.20.

(*ii*) As a reflector behind the source to direct light in a given area.

(*iii*) In the construction of astronomical telescopes.

Summary :—

CONCAVE MIRROR

Position of the object	*Position of the image*	*Nature of the image*	*Size of the image*
At infinity	At Principal focus	Real and inverted	Extremely diminished
Beyond Centre of curvature	Between Principal focus and centre of curvature	Real and inverted	Smaller size than the object
At Centre of curvature	Also at centre of curvature	Real and inverted	Same size as the object
Between principal focus and centre of curvature	Beyond centre of curvature	Real and inverted	Greater in size than the object
At Principal focus	At infinity	Real and inverted	Highly magnified
Between pole and principal focus	Behind the mirror	Virtual and erect	Magnified
At the pole	Also at the pole	Virtual, erect, laterally inverted	Same size at the object

CONVEX MIRROR

At infinity	*At focus*	*Virtual and erect*	*Extremely diminished*
Between infinity and pole of the mirror	Between pole and the focus	Always virtual and erect	Diminished

(*iv*) Used by doctors while examining the throat or the ear of a person. Also used in doctor's ophthalmoscope. Rays of light from a distant lamp are reflected by a concave mirror and concentrated on a throat or a tooth or inside the ear to illuminate it for examining it.

(*v*) Used in search light. If an electric bulb is kept at the focus of a concave mirror, then the reflected light comes out as a parallel beam and travels long distance. In an automobile the head lights or in a search light or in a hand torch, the reflectors are often concave mirrors.

(*vi*) Convex mirror is used as a driver's mirror on buses, trucks, cars, etc. [Fig. 5.21]

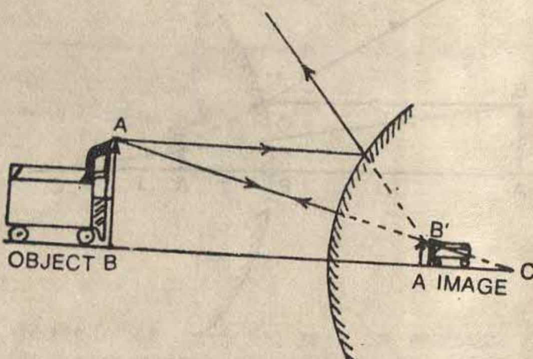


Fig. 5.21.

because Convex mirrors have a wider field of view and produce erect image.

(*vii*) Sun's rays are focused by large concave mirrors on the object to be heated.

SOLVED EXAMPLES

Example 1.

What will be the shortest size of a plane mirror which will enable a man 1·8 m high to see his full length image when the top of the mirror is 1·8 m from the ground ?

Solution.

CD is the image of the man *AB* (Fig. 5.22) in the plane mirror M_1M_2 such that

$$AB = CD$$

and $$AM_1 = M_1C$$

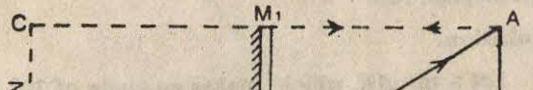


Fig. 5.22.

Join *D*, the image of the feet *B* to the eye at *A*. Let *DA* cut the plane mirror at M_2. Join M_2 to B. The path of rays by which the image of the feet B is seen by the eye *A* is shown by the arrow heads in Fig. 5.22. The shortest length of the mirror required to see the full length image is M_1M_2 which is given by

$$M_1M_2 = \tfrac{1}{2}CD \left[\because \text{ In } \triangle\ ACD,\ M_1 \text{ is the mid-point of } AC \text{ and } M_1M_2 \parallel CD. \right.$$
$$= \tfrac{1}{2}AB$$

$$= \tfrac{1}{2} \times 1{\cdot}8 = \mathbf{0{\cdot}9\ m}$$

Example 2.

Find the deviation produced by reflection at a plane mirror when the angle between the incident and reflected rays is 80°

Solution.

$$2i = i + r = 80^\circ$$

$$\text{Deviation} = 180^\circ - 2i = 180^\circ - 80^\circ = 100^\circ.$$

Example 3.

Rays of light strike a horizontal plane mirror at an angle of 45°. Show by a diagram how you would arrange a second mirror in order that the reflected ray may finally be directed from the second mirror horizontally.

Solution.

Let a ray *AB* strike the horizontal plane mirror OM_1 such that $\angle ABM_1 = 45^\circ$ and angle of incidence $ABN_1 = 45^\circ$ = angle of reflection CBN_1 where BN_1 is the normal to OM_1 at *B* (Fig. 5.23). Let the reflected ray *BC* strike the second plane mirror OM_2 in such a way that after reflection from it, it is finally directed horizontally along *CD*. Let *CN*, the normal to OM_2 at *C*, meet the normal BN_1 at *N*.

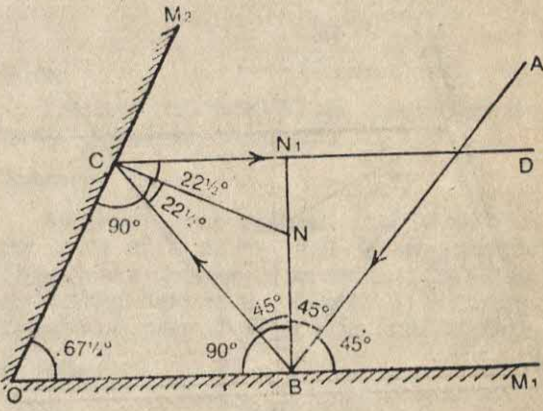


Fig. 5.23.

Since $OM_1 \parallel CD$ and $BN_1 \perp OM_1$

$\therefore$ $BN_1 \perp CD$ or $\angle BN_1C = 90^\circ$.

In the right-angled $\triangle\ BCN_1$,

$\because$ $\angle CBN_1 = 45^\circ$.

$\therefore$ $\angle BCN_1 = 45^\circ$.

Therefore, for the second plane mirror OM_2.

angle of incidence $= \angle BCN = \tfrac{1}{2}\angle BCN_1 = 22{\cdot}5^\circ$ $= \angle DCN$ = angle of reflection.

Now *OBNC* is a cyclic quadrilateral as $\angle OBN = 90^\circ = \angle OCN$. Hence, the angle between the two mirrors OM_1 and OM_2 is given by

$$\angle M_1OM_2 = \angle BOC$$
$$= 180^\circ - \angle BNC$$

$$=180°-[180-\angle CBN-\angle BCN]$$

$$=\angle CBN+\angle BCN$$

$$=45°+22{\cdot}5°=67{\cdot}5°.$$

Example 4.

Find the angle between two plane mirrors so that a ray incident on one and parallel to the other after reflection at the second is rendered parallel to the first.

Solution.

Let OM_1 and OM_2 be the two plane mirrors inclined to each other angle θ. (Fig. 5·24).

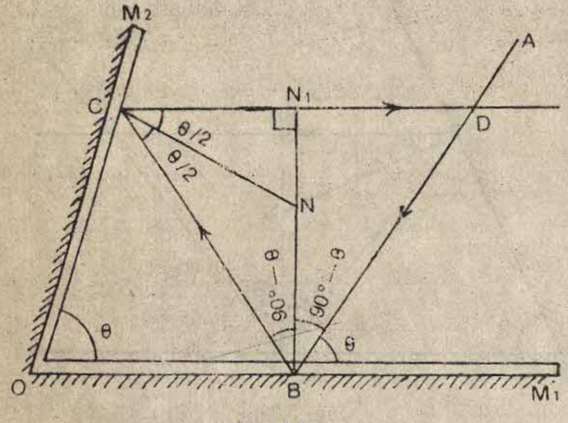


Fig. 5.24.

Let a ray AB which is parallel to OM_2 be incident on OM_1 at B. After reflection at B it goes along BC and strikes OM_2 at C in such a way that the reflected ray CD is parallel to OM_1.

Let the normals BN and CN drawn respectively to OM_1 at B and OM_2 at C meet each other at N. Let BN produced meet CD at N_1.

Since $AB \parallel OM_2$,

$\therefore\ \angle ABM_1=\angle M_2OM_1=\theta.$

$\therefore$ Angle of incident $=\angle ABN=90°-\theta$

$=\angle CBN=$ angle of reflection

Since $\triangle BCN_1$ is right-angled,

$\therefore\ \angle BCN_1=90°-\angle CBN_1=90°-\angle CBN$

$=90°-(90°-\theta)=\theta$

$\therefore$ For the second plane mirror OM_2.

Angle of incidence $=\angle BCN=\theta/2=\angle DCN$

$=$ angle of reflection.

Now $OBNC$ is a cyclic quadrilateral as $\angle OBN=90°=\angle OCN$. Hence, the angle between the mirrors is given by

$$\theta=\angle M_1OM_2$$

$$=\angle BOC$$

$$=180-\angle BNC$$

$$=180-[180-\angle CBN-\angle BCN]$$

$$=\angle CBN+\angle BCN$$

or $=(90-\theta)+\theta/2$

or $3\theta/2=90°$

or $\theta=60°$.

Example 5.

A ray of light makes an angle of 10° with the horizontal and strikes the mirror of a microscope which is inclined at 25° to the horizontal. Will the light be reflected vertically? If not, find the angle necessary to accomplish this.

Solution.

Let a ray AB, which makes an angle of 10° with the horizontal AH, strike the plane mirror M_1M_2 inclined at 25° to the horizontal AH and be reflected along BC as shown in Fig. 5.25. Thus,

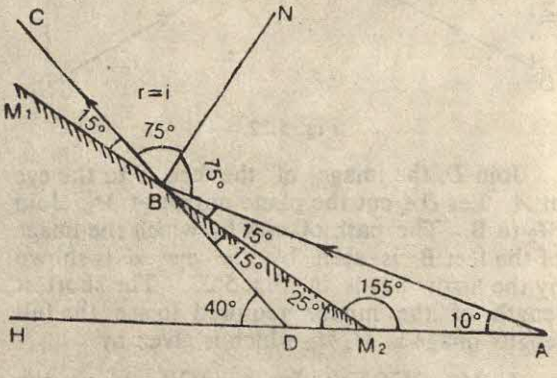


Fig. 5.25.

$$\angle BAH=10° \text{ and } \angle BM_2H=25°.$$

$$\angle AM_2B=180°-\angle BM_2H=180°-25°=155°$$

In $\triangle ABM_2$, $\angle ABM_2=180°-[\angle BAM_2+\angle AM_2B]$

$$=180°-(10°+155°)=15°$$

Thus, the incident ray makes an angle of 15° with the plane mirror M_1M_2. Consequently, the reflected ray BC also makes an angle of 15° with the plane mirror M_1M_2, *i e.*, $\angle M_1BC=15°$.

$\therefore \quad \angle M_2BD = \angle M_1BC$ [Being vertically opposite angles]

$$= 15^\circ.$$

In the $\triangle BDM_2$, the external $\angle HDB$

$$= \angle BM_2D + \angle DBM_2 = 25^\circ + 15^\circ = 40^\circ.$$

Thus, the reflected ray BC *makes an angle of 40° with the horizontal.*

If the reflected ray BC is to be thrown up vertically, it must be rotated through $90^\circ - 40^\circ = 50^\circ$. Hence the mirror must be rotated through half of this angle, *i.e.*, through 25°. The mirror should, therefore, make an angle of $25^\circ + 25^\circ = 50^\circ$ with the horizontal as shown in Fig. 5.26.

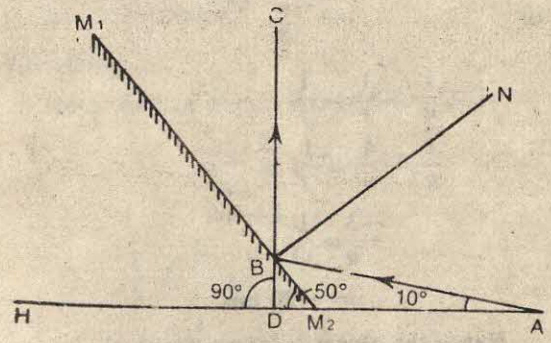


Fig. 5.26.

Use of Mirror Formula :

The following points will help the students in the solution of numerical problems based on mirror formula :

(*i*) Draw a rough diagram.

(*ii*) Remember the general mirror formula

$$\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$$

(*iii*) Put the numerical values of *u*, *v* and *f* with proper sign.

(*iv*) *Do not assign any sign to the unknown quantity which comes as a result of solution.*

(*v*) The linear magnification is negative for a real image which is inverted and downward and positive for virtual and erect image.

Example 6.

The focal length of a concave mirror is 15 cm. If the object is placed at a distance of 20 cm from the vertex of the mirror, where will the image be formed ?

Solution.

$$u = -20 \text{ cm}$$
$$v = ?$$
$$f = -15 \text{ cm}$$

Now $$\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$$

$\therefore$ $$\frac{1}{-20} + \frac{1}{v} = \frac{1}{-15}$$

or $$\frac{1}{v} = -\frac{1}{15} + \frac{1}{20}$$
$$= -\frac{1}{60}$$

or $$v = -\mathbf{60\ cm}$$

The image is formed 60 cm away from the vertex towards the object side.

Example 7.

An object is at a distance of 10 cm from the vertex of a mirror, and the image of the object is at a distance of 30 cm from the mirror on the same side as the object. Is the mirror concave or convex ? What is its focal length ?

Solution.

$$u = -10 \text{ cm}$$
$$v = -30 \text{ cm}$$
$$f = ?$$

Now $$\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$$

$\therefore$ $$-\frac{1}{10} - \frac{1}{30} = \frac{1}{f}$$

or $$-\frac{4}{30} = \frac{1}{f}$$

$$f = \frac{-15}{2} = -\mathbf{7{\cdot}5\ cm}$$

Since the focal length is negative, therefore the mirror is convave one.

Example 8.

A concave mirror of radius of curvature 12 cm forms a real image $\frac{3}{2}$ times the size of a given object. Find the relative positions of the mirror, object and image. With the same mirror and object, can any other position be obtained to give an image of the same size as before ?

Solution.

Radius of curvature $=R=-12$ cm

$$\therefore \quad f=-6 \text{ cm}$$

$$u=?$$

$$v=?$$

Size of the image $=I=3$

Size of the object $=O=2$

$$\because \quad \frac{v}{u}=\frac{I}{O}$$

$$\therefore \quad \frac{-v}{-u}=\frac{3}{2} \text{ (when the image is real)}$$

or
$$v=\frac{3}{2}\,u$$

$$\because \quad \frac{1}{u}+\frac{1}{v}=\frac{1}{f}$$

$$\therefore \quad \frac{1}{u}+\frac{2}{3u}=\frac{1}{-6} \qquad (\because \text{ it is a concave mirror})$$

or
$$\frac{5}{3u}=-\frac{1}{6}$$

or
$$3u=-30$$

or
$$u=-10 \text{ cm}$$

and
$$v=\frac{3}{2}\,u=-10\times\frac{3}{2}=-15 \text{ cm}$$

Second Position. We suppose that the image is virtual.

For a virtual image $=\dfrac{v}{-u}=\dfrac{3}{2}$ or $v=\dfrac{-3}{2}\,u$

Again,

$$\because \quad \frac{1}{u}+\frac{1}{v}=\frac{1}{f}$$

$$\therefore \quad \frac{1}{u}-\frac{2}{3u}=-\frac{1}{6}$$

or
$$\frac{1}{3u}=-\frac{1}{6}$$

or
$$3u=-6$$

$$\therefore \quad u=-2 \text{ cm}$$

Hence $v=3$ cm

This would give a virtual image of the same size as in the first case.

Example 9.

The image formed by a convex mirror of focal leagth 30 cm is a quarter of the object. What is distance of the object from the mirror ?

Solution.

$$f=+30 \text{ cm}$$

$$u=?$$

$$v=?$$

Size of the image $=I=1$

Size of the object $=O=4$

$$\because \quad \frac{v}{-u}=\frac{I}{O}$$

$$\therefore \quad \frac{v}{u}=-\frac{1}{4}$$

or
$$v=\frac{-u}{4}$$

$$\because \quad \frac{1}{u}+\frac{1}{v}=\frac{1}{f}$$

$$\therefore \quad \frac{1}{u}-\frac{4}{u}=\frac{1}{f}$$

$$\frac{-3}{u}=\frac{1}{30}$$

$$\mathbf{u=-90 \text{ cm}}$$

Hence the object is 90 cm from the vertex of the convex mirror.

Example 10.

An object 6 cm long is placed 1 metre in front of a concave mirror of 10 cm focal length. Find the nature and the size of the image.

Solution.

$$u=1 \text{ metre}=-100 \text{ cm}$$

$$v=?$$

$$f=-10 \text{ cm}$$

Size of the object $=O=6$ cm

Size of the image $=I=?$

$$\because \quad \frac{1}{u}+\frac{1}{v}=\frac{1}{f}$$

$$\therefore \quad \frac{1}{-100}+\frac{1}{v}=\frac{1}{-10}$$

or
$$\frac{1}{v}=-\frac{1}{10}+\frac{1}{100}$$

$$\therefore \quad v=\frac{-100}{9}=-11\frac{1}{9} \text{ cm}$$

Since v is negative, therefore the image is real and inverted.

Now $\frac{-I}{O}=\frac{v}{u}$ where I=Size of the image and O=Size of the object.

$$\therefore \quad \frac{-I}{6}=\frac{\frac{100}{9}}{100}$$

$$I=\frac{-100}{9}\times\frac{1}{100}\times 6=\frac{-2}{3}\text{ cm}$$

Example 11.

A candle is held 3 cm away from a concave mirror whose radius of curvature is 24 cm. Where is the image formed ? What is the nature of the image ?

Solution.

Here, Radius of curvature$=R=-24$ cm

$$\therefore \quad f=\frac{R}{2}=-12\text{ cm}$$

$$u=-3\text{ cm}$$

$$\because \quad \frac{1}{u}+\frac{1}{v}=\frac{1}{f}$$

$$\therefore \quad \frac{1}{v}=\frac{1}{f}-\frac{1}{u}$$

$$=\frac{1}{(-12)}-\frac{1}{(-3)}$$

$$=-\frac{1}{12}+\frac{1}{3}=\frac{1}{4}$$

$$\therefore \quad \boxed{v=4\text{ cm}}$$

Thus $\quad m=-\frac{v}{u}=-\frac{4}{(-3)}=\frac{4}{3}$

Hence the magnitude of m is greater than unity. *Hence the image is 4 cm behind the mirror. It is virtual, magnified and erect.*

Example 12.

How far should one hold an object from a concave mirror of focal length 40 cm so as to get an image twice the size of the object ?

Solution.

Here, $\quad f=-40$ cm

$\frac{I}{O}=\frac{v}{u}=2$ (for real and inverted image)

$$\therefore \quad v=2u$$

$$\because \quad \frac{1}{u}+\frac{1}{v}=\frac{1}{f}$$

$$\therefore \quad \frac{1}{u}+\frac{1}{2u}=\frac{1}{-40}$$

or $\quad \frac{3}{2u}=-\frac{1}{40}$

$$\therefore \quad \boxed{u=-60\text{ cm}}$$

For virtual and erect image,

$$\frac{I}{O}=\frac{v}{-u}=2$$

$$\therefore \quad v=-2u$$

$$\therefore \quad \frac{1}{u}-\frac{1}{2u}=-\frac{1}{40}$$

or $\quad \frac{1}{2u}=-\frac{1}{40}$

$$\therefore \quad \boxed{u=-20\text{ cm}}$$

Hence an object should be held at 60 cm from the vertex of the concave mirror for real and inverted image and at 20 cm from the concave mirror for virtual and erect image.

Example 13.

If a concave mirror of focal length 3 cm is held at a distance of 2 cm from a tooth, what is the magnification of the image ?

Solution.

Here, $\quad f=-3$ cm

$u=-2$ cm

$v=?$

$m=?$

$$\frac{1}{u}+\frac{1}{v}=\frac{1}{f}$$

$$\frac{1}{-2}+\frac{1}{v}=\frac{1}{-3}$$

$$\therefore \quad \frac{1}{v}=-\frac{1}{3}+\frac{1}{2}=\frac{1}{6}$$

$$\therefore \quad v=6\text{ cm}$$

Magnification$=m=-\frac{v}{u}=-\left[\frac{6}{-2}\right]=3$

Example 14.

An object is at a distance of 5 m from a convex mirror of focal length 10 cm. Where is the image formed and what is its magnification ?

Solution.

Here, $u=-5\text{ m}=-500\text{ cm}$

$f=10\text{ cm}$

$v=?$

$m=?$

Since $\frac{1}{u}+\frac{1}{v}=\frac{1}{f}$

$$\therefore\ \frac{1}{-500}+\frac{1}{v}=\frac{1}{10}$$

$$\frac{1}{v}=\frac{1}{10}+\frac{1}{500}=\frac{51}{500}$$

$$\therefore\ v=\frac{500}{51}\text{ cm}$$

$$=9{\cdot}8\text{ cm}$$

$$\text{Magnification }=m=-\frac{v}{u}$$

$$=-\left[\frac{9{\cdot}8}{-500}\right]$$

$$=0{\cdot}0196$$

Example 15.

An object is located 20 cm in front of a concave mirror of radius of curvature 50 cm. Where is the image formed and what is its nature ?

Solution.

Here, $u=-20\text{ cm}$

$R=-50\text{ cm}$

$$\therefore\ f=\frac{R}{2}=-25\text{ cm}$$

$v=?$

Now $\frac{1}{u}+\frac{1}{v}=\frac{1}{f}$

$$\therefore\ \frac{1}{-20}+\frac{1}{v}=\frac{1}{-25}$$

$$\frac{1}{v}=-\frac{1}{25}+\frac{1}{20}$$

$$=\frac{1}{100}$$

$$\therefore\ v=100\text{ cm}$$

Hence the image is virtual and erect.

$$\text{Magnification }=m=-\frac{v}{u}=-\left[\frac{100}{-20}\right]=5$$

Thus the image is 100 cm behind the mirror, magnified five times and it is virtual and erect.

SUMMARY

1. A light beam passing through any material medium will become progressively weaker due to two effects. Part of its energy will be *absorbed* by molecules of the medium and part will be *scattered* in all directions by them. A light beam striking the boundary between two media can be partly transmitted and partly returned to the first medium. Light returned to the first medium is said to be *reflected* at the boundary.

2. **Laws of reflection**

   (*i*) The angle of incidence (*i*) is equal to the angle of reflection (*r*).

   (*ii*) The incident ray, the reflected ray, and the normal to the reflecting surface lie in the same plane.

3. Any highly polished surface which reflects most of the light that falls on it is called a mirror.

4. *Plane* mirrors of plate glass are silvered on one surface to reflect light efficiently and their reflectance is quite high.

5. The rays of the sun reaching the earth are practically parallel and thus have the same angle of incidence. They remain practically parallel after being reflected from a plane mirror. Such reflection, in which scattering of the reflected rays is negligible, is called *regular* reflection. Polished surfaces cause regular reflection and the image of the luminous source is sharply defined. Searchlights, beacons and automobile spotlights use concentrated light sources of high intensity and highly polished regular reflectors to redirect light rays in the desired direction.

6. When a beam of light is incident on an irregular surface, the laws of reflection hold true for each particular ray of light, but the normals to the surface are not parallel, and the light is reflected in many directions. Such *scattering* or *diffusion* of light is extremely important.

7. The image formed by a plane mirror

   (*a*) is neither enlarged nor reduced. The image is of the same size as the object.

   (*b*) is always virtual, erect and appears as far behind the mirror as the object is infront of it.

   (*c*) differs from the object in that right and left are interchanged *i.e.*, the image is *laterally inverted.* This means the image of the right hand has the appearance of a left hand. If an object is spinning clockwise about its axis, its image appears to be spinning counter-clockwise about its image axis.

8. An image formed by rays or light actually passing through the image point is called a **real image.** Real images are inverted relative to the object and can be larger or smaller than the object. Real image can be obtained on a screen.

   An image formed by rays of light which appear to have diverged from the image point and do not actually pass through that point is called a **virtual image.** Virtual images cannot be projected on a screen. They are erect with respect to the object ; they can also be enlarged or reduced in size.

9. Besides plane mirrors, we have mirrors which are curved. The laws of reflection hold for the curved mirrors also.

   Spherical mirrors, the surfaces of which are sections of spheres, are commonly used for special purposes. The size and position of the images formed are quite different from those of the images formed by plane mirrors.

10. When the mirror is a portion of the polished *outer* surface of a sphere, it is said to be *convex.* The reflecting surface is curved towards the observer.

    When the mirror is a portion of the polished *inner* surface of a sphere, it is said to be *concave.* Here the reflecting surface is curved away from the observer.

11. The *centre of curvature* is the centre of the sphere of which the mirror forms a part. The *aperture* is a measure of the portion of the sphere included by the mirror. Only a small section of the total surface of the sphere is used as the reflecting surface for clear image formation.

    The *vertex* (or the pole) is the centre of the mirror itself.

    The *principal axis* is the line drawn through the centre of curvature and the vertex.

    A *secondary axis* is any other line drawn through the centre of curvature.

    A ***normal*** to the surface of a concave mirror is a radius drawn from a point of incidence. (The radius is perpendicular to the tangent to the surface drawn through the point of incidence.) In a convex mirror, a normal is a radius produced or extended beyond the mirror.

    The point on the principal axis to which rays parallel to the principal axis converge (or from which they diverge) is known as the *principal focus.* The distance between the principal focus and the vertex is called the *focal length* of the mirror.

12. **Focal length** of a spherical mirror is half its radius of curvature

$$f=\frac{R}{2}.$$

13. Since incident rays diverge on being reflected, convex mirrors are known as ***diverging*** mirrors.

14. **Graphical Method** (concave mirror) :

    We can construct the image formed by a concave mirror by **locating the images** of enough different points. Concave mirror images may be grouped into **six cases.**

    Case 1. *Object at infinite distance.*

    The image formed by a concave mirror is a point at the **principal focus.**

    Case 2. *Object at finite distance beyond the centre of **curvature**.*

    The image in this case is real, inverted, reduced and **located between the centre of curvature** and the principal focus.

    Case 3. *Object at the Centre of curvature.*

    The image is real, inverted, the same size as the object, and located at the centre of curvature.

    Case 4. *Object between the centre of curvature and principal focus.*

    The image is real, inverted, enlarged and located beyond the centre of curvature.

    Case 5. *Object at principal focus.*

    The image is real, inverted, highly enlarged and lies at infinity.

    Case 6. *Object between principal focus and mirror.*

    The image is virtual, erect, enlarged and located behind the mirror.

15. In constructing ray diagrams for convex mirrors we proceed as for concave mirrors except that the four rays of importance are the following :

   (*i*) A ray that is parallel to the axis and which is reflected as if it came from the virtual principal focus of the mirror.

   (*ii*) A ray that is heading toward the virtual principal focus and which is reflected parallel to the principal axis (by the principle of reversibility of rays).

   (*iii*) A ray that is heading toward the vertex of the mirror and which is reflected so that the angle of reflection with respect to the principal axis is equal to the angle of incidence

   (*iv*) A ray that is heading toward the centre of curvature of the mirror and which is reflected directly back on itself.

   These four rays enable the image of any point on an object to be located for a convex mirror. In a convex mirror, all images are virtual, erect, smaller than the object and located behind the mirror between the vertex and the principal focus. The size of the image increases as the object moves closer to the mirror, but it can never become as large as the object itself.

16. A simple relationship exists between the distance of an object (u) from a curved mirror, the distance of its image (v) and the focal length (f) of the mirror. This relationship, known as the *mirror equation* is as follows :

$$\frac{1}{u}+\frac{1}{v}=\frac{1}{f}$$

   The mirror equation is applicable to all concave and convex mirrors.

17. The image of an object formed by a spherical mirror can be larger or smaller than the object. It may be inverted or erect, real or virtual. It depends upon the position of the object relative to the mirror and nature of the spherical mirror employed.

18. Lateral magnification is the ratio of the height of the image to that of the object.

$$m=\frac{I}{O}=-\frac{v}{u}$$

   The magnitude of m can be greater or less than unity depending upon the values of u and v.

19. Spherical mirrors have varied practical applications in everyday life.

QUESTIONS

[A] Objective Type Questions

1. When parallel rays are reflected from a smooth, plane surface, the reflected will be
   (*a*) parallel to the incident rays
   (*b*) parallel to each other
   (*c*) non-parallel
   (*d*) part of a spherical surface
2. When light is diffusely reflected, the angle of reflection is
   (*a*) greater than
   (*b*) less than
   (*c*) equal to the angle of incidence
3. A person approaches a plane mirror with a speed of 7 ms^{-1}. His image approaches him with a speed, in metre per second, of
   (*a*) 0
   (*b*) 7
   (*c*) 14
   (*d*) 21
4. As a person approaches a plane mirror, the size of his image
   (*a*) increases
   (*b*) decreases
   (*c*) remains the same

5. **If a ray of light falls on a rough surface, the angle of reflection of this ray.**
   - **(*a*) is less than the angle of incidence**
   - **(*b*) is greater than the angle of incidence**
   - **(*c*) is equal to the angle of incidence**
   - **(*d*) may be any of the previous three**

6. **The glass of some electric light bulbs is frosted so that the glass will be**
   - **(*a*) opaque**
   - **(*b*) transparent**
   - **(*c*) translucent**
   - **(*d*) non-refracting**

7. **The paper does not act as a mirror because the light falling on it is**
   - (*a*) transmitted
   - (*b*) absorbed
   - (*c*) diffusely reflected
   - (*d*) regularly reflected

8. **An object is 30 cm from a concave spherical mirror whose focal length is —20 cm. The image is**
   - (*a*) virtual and enlarged
   - (*b*) virtual and reduced in size
   - (*c*) real and reduced in size
   - (*d*) real and enlarged

9. **The radius of curvature of the mirror in question (8) is ....cm.**

10. **Which mirror has a wider field of view :**
    - (*a*) concave mirror
    - (*b*) convex mirror
    - (*c*) plane mirror

11. **An image formed by a convex mirror is always**
    - (*a*) virtual, erect and diminished
    - (*b*) virtual, real and magnified
    - (*c*) real, inverted and diminished
    - (*d*) real, erect and magnified

12. **In the case of a concave mirror, match the items in Column B against the items in Column A.**

Column A	**Column B**
(Position of object)	**(Position of image)**
(*a*) Very far away	**(*i*) Very far away**
(*b*) At *C*	**(*ii*) Between *F* and the vertex**
(*c*) Between *F* and the vertex	**(*iii*) At *C***
(*d*) Beyond *F* and *C*	**(*iv*) Between F and *C***
(*e*) At *F*	**(*v*) At *F***
(*f*) Beyond *C*	**(*vi*) Beyond C on the same side as the object.**
	(*vii*) On the other side of the mirror *i.e.*, behind

Very Short Answer Questions

1. Does light travel in a curved path ?
2. Do all bodies absorb light ?
3. A ray of light falls normally on a plane mirror, what will be the angle of reflection ?
4. If a parallel beam of light falls on a blotting paper, will the reflection from the blotting paper be regular or irregular ?
5. What type of image is usually formed by a plane mirror ? Can it also form real image ?
6. Does the right hand side of the object appear right hand side of the image in a plane mirror ? Is the image erect or inverted ?
7. What type of image is formed by a convex mirror ?
8. What type of image is formed by a concave mirror when the object lies between the principal focus and the pole of the mirror ?
9. What is the relation between f and r of a spherical mirror ?
10. What is the radius of curvature of a plane mirror ?
11. What is the focal length of a concave mirror of—30 cm radius of curvature ?
12. A concave mirror of—20 cm focal length forms an image of the same size as the object, what is the position of object ?
13. A toy car runs towards a plane mirror with a velocity of 2 m/sec. At what rate its image runs towards it ?

Short Answer Type and Essay Type Questions

1. State three things that may happen to a beam of light striking a body. Which of the three is most likely to occur when a beam of light strikes the following :—

   (*a*) a plane mirror.
   (*b*) a plane glass.
   (*c*) a polished table.
   (*d*) coal tar.
   (*e*) a perfectly transparent body.
   (*f*) a piece of diamond.
   (*g*) a black cloth.
   (*h*) water.
   (*i*) strained glass.

2. You can see your face in a polished top of a table, but you cannot see it when it is not polished. Explain.
3. (*a*) State the laws of Reflection of light.

   (*b*) How will you verify these laws experimentally ?

4. (*a*) Define an optical image.

   (*b*) Distinguish between a real image and a virtual image. Give examples.

   (*c*) Is the image produced by a plane mirror real or virtual ; erect or inverted ; enlarged, the same size or smaller ?

(*d*) If a word was written on a thin sheet of paper, explain how you would use a plane mirror to read the word from the back of the paper.

5. (*a*) An object is placed 5 cm in front of a mirror. Show by means of a diagram the two ways in which you can find the position of the image.

(*b*) Draw a ray of light incident at 45° on a plane mirror. Draw the normal and the reflected ray. What is the angle of deviation of ray ?

(*c*) Draw an arrangement by which a ray could be turned through a right angle by a plane mirror. Show how this is used in practice. Name the instrument and where is the instrument used ? **[Hint :—Periscope]**

6. A boy uses a mirror to flash a beam of light into the teacher's eyes, and he gets caught immediately. Why ?

7. (*a*) What is spherical mirror ?

(*b*) Distinguish between a concave mirror and a convex mirror.

(*c*) How can you tell the difference between a concave and a convex mirror by looking at your face in each ?

8. Define ; Principal axis ; vertex ; principal focus ; centre of curvature ; focal length of a spherical mirror giving diagram.

(*b*) What is the relationship between radius of curvature and focal length of a spherical mirror ? How will you derive it ? Mention the various assumptions used.

9. (*a*) Define centre of curvature and radius of curvature of a spherical mirror.
(*b*) Derive the formula

$\frac{1}{u}+\frac{1}{v}=\frac{1}{f}$ for a spherical mirror where the symbols have their usual meanings.

Mention the **sign conventions** and assumptions used.

10. (*a*) Describe how a concave mirror can be used (*a*) to burn a piece of tissue paper, (*b*) to send out a parallel beam of light.

11. Use diagrams to show why concave mirrors are called converging mirrors while convex mirrors are called diverging mirrors.

12. Describe the series of images formed by (*a*) a concave mirror, (*b*) a convex mirror, as the mirror is moved from a position near the face to about 100 cm away.

13. (*a*) Mention the various uses of spherical mirrors.
(*b*) What advantages, as a driver's mirror, does a convex mirror have over a plane mirror ? [*A.I.S.S.E. 1979, 1986*]

14. (*a*) How will you demonstrate that light travels in straight lines ?

(*b*) Draw a diagram to show how a tiny hole can produce an image on a screen. What is the name given to the instrument which uses this method to take photographs of objects ?

15. In the pin-hole camera :

(*a*) What would you do to increase the size of the image on the screen ?

(*b*) What would you do to increase the size of the brightness of the image ?

(*c*) What would you do to make the image sharpen ?

(*d*) Is the image produced real or virtual ; erect or inverted ; enlarged, the same size or smaller ?

16. (*a*) What is magnification produced by a spherical mirror ? Derive an expression for it for a concave mirror.

(*b*) What changes would you observe in your image as you move nearer to (*a*) a plane mirror, (*b*) a concave mirror, (*c*) a convex mirror ?

17. Does a woman really need a full length mirror in her house ? How would you proceed to convince her (scientifically) that she does not ?

18. (*a*) Why does a cheap looking glass give a disorted image ?

(*b*) Why is twi-light visible after sunset ?

(*c*) How can a narrow room be made to appear very spacious ?

(*d*) Why do the images of trees appear to be inverted in water by the river-side ?

(*e*) How would you arrange two plane mirrors to see the back of your head ? Illustrate by a diagram.

(*f*) A lady wishing to pin a flower on the right side of her head, pins it on the left side while looking into the mirror. Explain why ?

(*g*) For what purpose does a surgeon use a concave mirror ?

(*h*) Where should an object be placed infront of a concave mirror to obtain its magnified erect image ? [*A.I.S.S.E. 1982*]

19. Incident ray remaining the same, whenever a plane mirror is rotated through a certain angle θ, show that the reflected ray gets rotated through an angle 2θ.

20. Draw the ray diagram to show the image formation of a vertical object placed on the principal axis, of a concave mirror, outside its centre of curvature.
Use this figure to derive a relation between object distance, image distance and the focal length. [*A.I S.S.E. 1986*]

Hints :

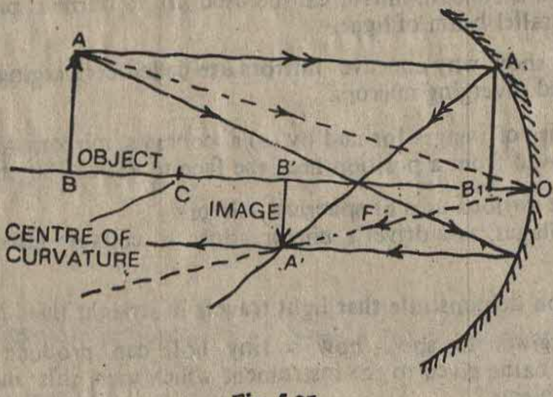


Fig. 5.27

Δs AOB and $A'OB'$ are similar

$$\therefore \qquad \frac{AB}{A'B'} = \frac{OB}{OB'} \qquad \ldots(1)$$

Similarly, Δs A_1B_1F and $A'B'F$ are similar

$$\therefore \qquad \frac{A_1B_1}{A'B'} = \frac{B_1F}{B'F} \qquad \ldots(2)$$

From A_1, drop A_1B_1 perpendicular on the principal axis.

Then, $A_1B_1=AB$ (distance between two parallel lines)

and $B_1F=OF$ (since the mirror has a small curvature hence B_1 and O lie very close to each other.)

Hence
$$\frac{AB}{A'B'}=\frac{OF}{B'F} \quad \ldots(3)$$

From equations (1) and (3)
$$\frac{OB}{OB'}=\frac{OF}{B'F} \quad \ldots(4)$$

Using the sign conventions, we have
$$OB=-u\,;\ OB'=-v$$
$$OF=-f\,;\ B'F=OB'-OF=-v-(-f)$$

Putting these values in (4)
$$\frac{-u}{-v}=\frac{-f}{-v-(-f)} \quad \text{or} \quad \frac{u}{v}=\frac{-f}{-v+f}$$
$$-uv+uf=-vf$$

Dividing both sides by uvf, we have
$$-\frac{1}{f}+\frac{1}{v}=-\frac{1}{u}$$

or
$$\frac{1}{u}+\frac{1}{v}=\frac{1}{f}$$

21. You are given three mirrors of equal size one concave, one convex and one plane. How will you identify them without touching their surface ?

22. Show that if a person approaches a plane mirror with a speed x, the image approaches the person with a speed $2x$.

23. Using a concave mirror, a screen and a measuring scale in broad day light, how will you find the height of a tree ?

Hints :

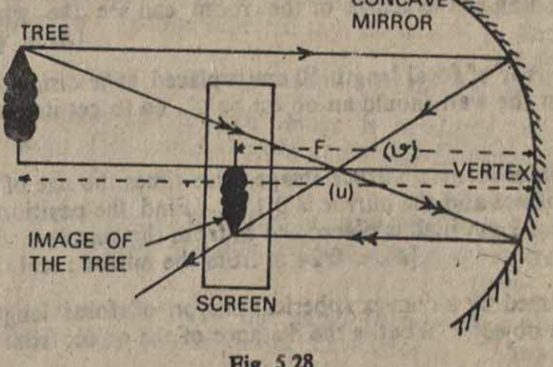


Fig. 5.28

$$\frac{\text{Size of the Image}}{\text{Size of the object}}=\frac{I}{O}=\frac{v}{u}$$

24. **What three factors determine the amount of light an object will reflect ?**

[Hints. (*i*) **kind of material underlying the surface**
(*ii*) **smoothness of the surface**
and (*iii*) **the angle at which the light strikes it.]**

25. **When you look in a plane mirror, do you see yourself as others see you ? Explain.**

26. (*a*) **Construct a ray diagram to show the formation of an image by a convex mirror.**
(*b*) **Describe fully the image that is formed.**

27. **What kind of mirror produces** (*a*) **a short, fattened image ;** (*b*) **a tall, thin image ?**

28. **Suppose we write the word "light" on a mirror with white paint. When the mirror is placed in a beam of sunlight, the reflection of the sunlight on a smooth wall consists of a bright area in which the letters of the word "light" appear dark. Explain.**

29. What kinds of mirrors could be used and where should the object be placed to produce
(*a*) an enlarged real image (*b*) a reduced real image
(*c*) a real image, the same size as the object (*d*) an enlarged virtual image
(*e*) a reduced virtual image ?

30. **Construct a ray diagram to show the formation of an image by a concave mirror when the object is at a finite distance beyond the centre of curvature. Describe fully the image that is formed.**

31. **Construct a ray diagram to show the formation of an image by a concave mirror when the object is between the principal focus and the centre of curvature. Describe fully the image that is formed.**

32. Starting from a large distance, a flame is slowly moved towards a convex mirror. Comment on how the size and position of the image change. [*A.I.S S. 1987*]

PROBLEMS

1. **A ray of light is incident at an angle of 60° to the mirror. What is the angle between the incident and the reflected ray ? The mirror is, now turned through 10°. By using a diagram find out the angle between the reflected ray in its new direction and the reflected ray before the mirror was turned.** **[Ans. 60° ; 20°]**

2. **Find the minimum size of a plane mirror, hung on a wall of a room, in which an observer, standing at the centre of the room can see the whole height of the wall behind him.** **[Ans. ⅓rd of the size of the wall]**

3. **A concave mirror of focal length 10 cm is placed at a distance of 0·35 m from a wall. How far from the wall should an object be placed to get its real image on the wall ?** **[Ans. 0·21 m]**

4. **A concave mirror forms a virtual image three times the size of the object, when distance between the object and the mirror is 0·1 m. Find the position and size of the image when an object 3 cm high is placed 0·4 m from the mirror.**
[Ans. 0·24 m from the mirror : real, inverted and 1·8 cm high]

5. **The image formed by a convex spherical mirror of focal length 0·3 m is a quarter of the size of the object. What is the distance of the object from the mirror ?** **[Ans. 0·9]**

6. **A concave mirror has a radius of 1 m. Where must the object be placed so that its image is formed at a distance of 1 m from the vertex of the mirror ?** **[Ans. 1 m]**

7. Find the deviation produced by reflection at a plane mirror when the angle of incidence is 35°. [Ans. [110°]

8. The distance of the pin-hole from the screen is 20 cm. It is required to get the image of a building 10 m high, on a screen. The screen is 15 cm high. What should be the distance of the pin-hole from the building ? [Ans. 13·33 m]

9. A man is running away from a plane mirror at the rate of 2 m per second. With what speed is he receding away from his own image ? [Ans. 4 ms^{-1}]

10. Two plane mirrors are placed parallel to each other and spaced 20 cm apart. A luminous point is placed between them and 5 cm from one mirror. Determine the distance from each mirror of three nearest images in each [Ans. 5, 35, 45 cm ; 15, 25, 55 cm]

11. An object 2·5 cm long is placed on the axis of a concave mirror of 30 cm radius of curvature at a distance of 10 cm from it. Find the position, size and nature of the image formed. [Ans. Virtual erect 30 cm behind the mirror ; 7·5 m]

12. An object is 10 cm from a convex mirror of focal length 20 cm. Find the position and nature of the image. [Ans. 6·67 cm ; Virtual and erect] [*D.B.S.S. 1978*]

13. An object is placed at a distance of 4 cm from a concave mirror of focal length 12 cm. Find the position and nature of image. [Ans. 6 cm ; Virtual and erect] [*D.B.S.S. 1979*]

14. A concave mirror produces a real image of height 2 cm of an object of height 0·5 cm placed 10 cm away from the mirror. Find the position of the image and focal length of the mirror. [Ans. —40 cm ; —8 cm] [*D.B.S.S. 1980*]

15. An object 1 cm high is placed on the axis of and 15 cm from a concave mirror of focal length 10 cm. Find the position, nature, magnification and size of the image. [Ans. 30 cm ; Real and Inverted ; —2 and 2 cm] [*D.B.S.S. 1981*]

16. The focal length of a concave mirror is 6 cm. An object is placed at a distance of 10 cm from its vertex. Where is the image formed ? [Ans. 15 cm away from the vertex towards the object side]

17. A convex mirror of focal length 10 cm is given. If an object is placed 15 cm away from the vertex of the mirror, where is the image formed and what is the magnification. [Ans. 6 cm ; 0·4]

18. A ray of light is incident at an angle of 60° on a horizontal plane mirror. At what angle should the mirror be tilted to make the reflected ray horizontal ? Draw the ray diagram. [*A.I.S.S.E. 1986*] [Ans. The mirror should be tilted at an angle of 15°]

19. A convex mirror has a focal length of 20 cm. An image is produced which is two-thirds of the length of the object. Determine the object distance from the mirror. [Ans. 10 cm]

20. The image of an object in a concave mirror of radius of curvature 20 cm is erect and is formed 30 cm from the mirror. Calculate the object distance from the mirror and the magnification. [Ans. 7·5 cm ; 4]

21. An object and its image in a concave mirror are the same height when the object is 6·4 cm from the mirror. What is the focal length of the mirror ? [Ans. 18·2 cm]

CHAPTER 6

Refraction of Light

6.1. INTRODUCTION

You learnt earlier that light can pass through air, through a vacuum and through transparent and translucent substances. Anything through which light passes is known as a medium. You already know, also, that in each of these media light travels in a straight line.

In this chapter you are going to find out what happens to the path of light as it goes from one medium into another.

You will also see how important it is to study this effect on the path of light, as on it depend most of the optical instruments we use every day, *e.g.*, spectacles, microscopes and telescopes, the human eye etc. This chapter should therefore be of tremendous interest to you.

6.2. PHENOMENON OF REFRACTION

When a pencil of light passes more or less obliquely from the transparent medium into another, as, for instance, from air into glass, it undergoes a deflection from its straight path, as shown in Fig. 6.1, which represents a ray of light passing from air into water. This change in direction is called **refraction**, from a Latin word, meaning *broken*; for the ray is actually broken at the point *O*, where it enters into water.

The ray *PO* is called the *incident ray* and *OR* the *refracted ray*. The angle *PON*. which the incident ray makes with the normal *MN* at the point of incidence to the surface *AB*, separating the two media, is called the *angle of incidence* and the angle *ROM* the *angle of refraction*.

The phenomenon of refraction can be demonstrated by a number of experiments, a couple of which are given below.

Experiment. Allow a beam of solar light, passing through a shutter in a dark room, to fall on a glass vessel, containing water, (Fig. 6.2). The beam will be seen very distinctly to

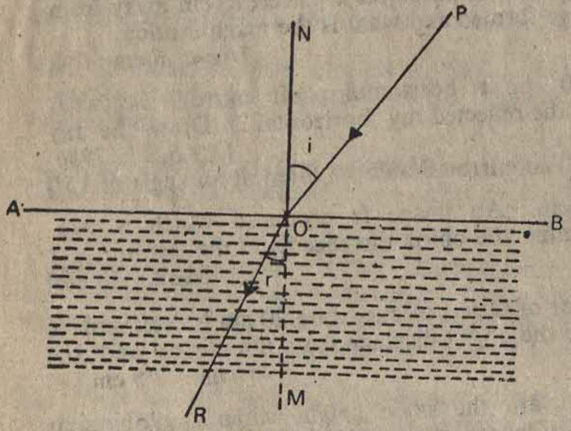


Fig. 6.1.

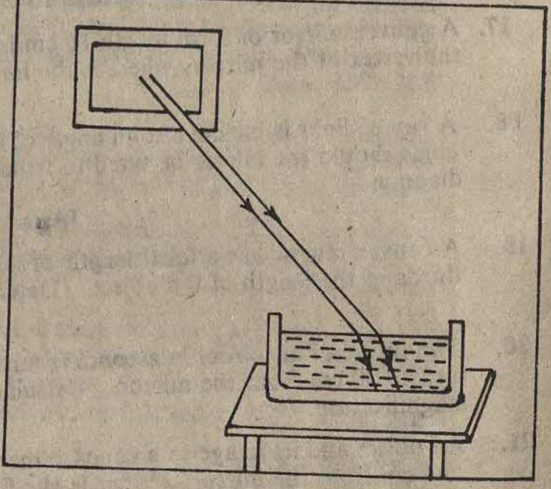


Fig. 6.2

have broken, while passing from air into water, especially if some light powder has been diffused through the air and the water so as to make the beam more visible.

Experiment 2. Place a coin at the bottom of a basin and move back from the vessel until the coin is just hidden below the upper edge of the side (Fig 6.3). Pour some water into the basin, the coin will now be visible. This is due to the fact that the rays from any point, such as *P* on the coin, cannot enter the eye when there is no water in the basin ; when however, water is poured into it, these rays from *P* get bent, as shown, on emerging from the water, and enter the eye, appearing to diverge from a point *P′* nearer to the water surface than *P*.

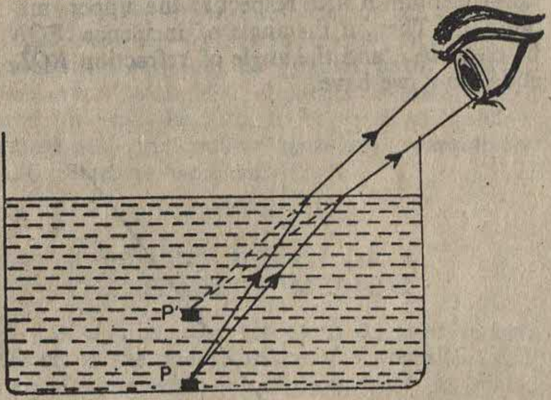


Fig. 6.3.

6.3. REFRACTING SUBSTANCES.

When a ray of light enters from one medium into another, it is in some cases, bent towards the normal, forming an angle of refraction, which is less than the angle of incidence, as, for example, when it passes *from air into glass or water.* In other cases, on the other hand, it is bent away from the normal and the angle of refraction is greater than the angle of incidence, as, for example, when it passes *from glass or water into air.* In the first case, the second medium is said to be more refracting than the first and, in the second case, less so. Among the most refracting substances are *water, alcohol, ether* and *diamond. Gases in general, are less refracting than water.* It is found generally *that when light passes from an optically rarer into an optically denser medium, it is bent towards the normal and when it passes from a denser into a rarer medium, it is bent away from the normal.*

Below is a list of a few substances in the order of their abilities to bend light, starting from the most powerful :

1. Diamond
2. Glass (the different types)
3. Glycerine and Turpentine
4. Water
5. Ice

Glycerine bends light almost to the same extent as glass, and that explains why it is used in microscopic work in joining two lenses together, as you will learn later.

6.4. LAWS OF REFRACTION

Refraction takes place according to two laws, analogous to the laws of reflection.

1. *The incident ray, the refracted ray, and the normal to the surface of separation at the point of incidence, lie in the same plane.*

2. *Whatever the obliquity of the incident ray, the ratio of the sine of the angle of incidence to the sine of the angle of refraction is a constant quantity for any two given media.* This is often spoken of as **Snell's law of refraction.**

Thus, in Fig. 6.1, $\frac{\sin PON}{\sin ROM}$ is a constant, no matter what the value of $\angle PON$ is. This constant is called the **refractive index** *of the second medium with respect to the first,* and is denoted by the letter *n*. Hence,

$$\frac{\sin PON}{\sin ROM}=\frac{\sin i}{\sin i}=n,$$

where *i* and *r* denote the angles of incidence and refraction respectively.

For all transparent solids and liquids, *n* is greater than 1. Its value for water is 1·333 and for crown glass, 1·52 varying slightly with the nature of the glass.

Refractive index *n* of a medium can also be expressed as the ratio of the speed of light in vacuum (or in air) to the speed of light in the given medium. Speed of light in vacuum (or in air) is 3×10^8 m/s.

6.5. EXPERIMENTAL VERIFICATION OF THE LAWS OF REFRACTION.

The laws of refraction can be verified in the following manner ;

Place a glass slab on a drawing board and draw its outline Fig. 6.4. Fix two pins *P* and

O, so that the line joining their feet is inclined to the face *AB* of the slab. Look from the opposite side *DC* and fix two more pins *R* and *S*, in a straight line with the images of *P* and *O*. Remove the slab and join *PO* to meet the face *AB* at *E* and *RS* to meet the face *DC* at *F*. Join *EF* and draw normals *GN* and *ML* at E and *F* respectively. Then *PO* is the *incidence ray*, *EF*, the *refracted ray*, and *RS*, the *emergent ray*. Measure the angle of incidence *PEG* and the angle of refraction *NEF*; it will be seen that the angle of refraction is smaller than angle of incidence, showing thereby that *the ray is refracted towards the normal, on passing from the rarer into the denser medium*. It will also be seen that the incident ray, the refracted ray and the normal lie *in the plane of the paper*, thereby proving the first law of refraction. Also, find the ratio *sin i/sin r* and see that it is equal to 1·5, the refracting index of glass. Repeat the above experiment for four or five different angles of incidence and see that the ratio *sin i/sin r* is the same, in all cases, thus verifying the second law or *Snell's law of refraction.*

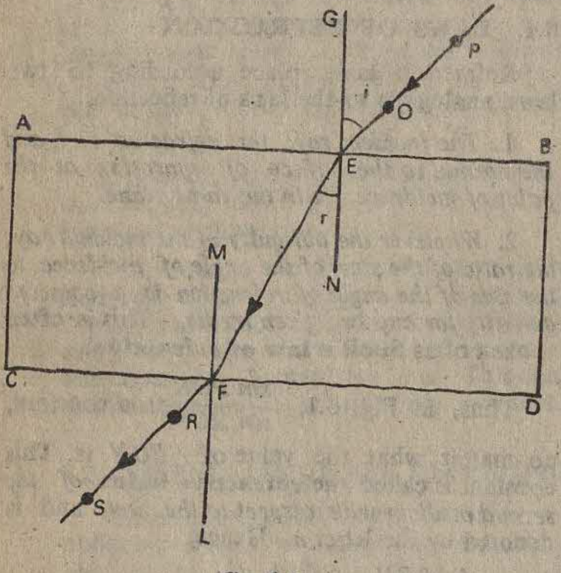


Fig. 6.4.

6.6. REVERSIBILITY OF THE PATH OF LIGHT

Let *AB* be the section of a plane surface separating two media, *a* and *b*, of which *b* is the denser one and let a ray *PQ* (Fig. 6.5), incident at a point *Q* give rise to the refracted ray *QR* in the medium. If we now reverse the ray *QR* by reflecting it normally from a plane mirror *M*, the reversed ray *RQ* gives rise to the refracted ray, travelling along the path *QP* in the upper medium *a*. The same principle holds good in the case of reflection ; thus, in (Fig. 5.7), if the reflected ray *CRS* be reversed, as explained above, it will give rise to a reflected ray, travelling along the path *CQP*, which is the same as that of the original incident ray, but in the *opposite* direction. This principle is known as the **principle of reversibility** of the path of light and states that *if light after suffering any number of reflections and refractions, has its final path reversed, it travels back along the same path, in the opposite direction.*

Let $^a n_b$ be the index of refraction of the lower medium *b* with respect to the upper medium *a*. Then, if the angle of incidence *PQN* be equal to *i*, and the angle of refraction *RQL*, equal to *r*, we have

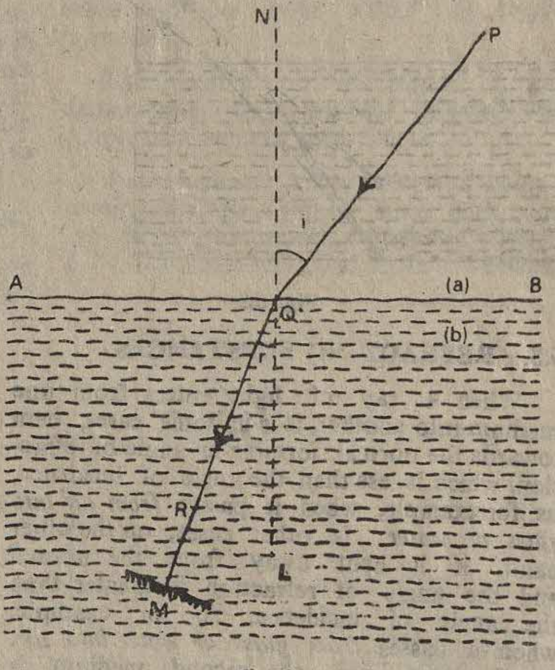


Fig. 6.5

$$^a n_b = \frac{\sin i}{\sin r} \qquad \cdots(i)$$

On reversing the ray *QR*, the new angle of incident at *Q* is equal to *r*, while the angle of refraction is equal to *i*. Now, if $^b n_a$ is the index of refraction of the upper medium *a* with respect to the lower medium *b*, we have

$${}^{b}n_{a}=\frac{\sin r}{\sin i} \qquad \ldots(ii)$$

Multiplying together the corresponding sides of (*i*) and (*ii*), we get

$\therefore \quad {}^{a}n_{b}\times{}^{b}n_{a}=1$, whence, ${}^{a}n_{b}=1/{}^{b}n_{a}$.

Thus, the index of refraction of a medium **a** *with respect to another medium* **b** *is equal to the reciprocal of the index of refraction of* **b** *with respect to* **a**.

6.7. LAWS OF REFRACTION FOR SMALL ANGLES OF INCIDENCE

When light is incident *normally* on a refracting surface, $i=0$, and, therefore,

$\sin i=0$, but $\sin i=n \sin r$

$\therefore \quad n \sin r=0$, or, $r=0$.

Thus, *when light falls normally* on a refracting surface, no refraction takes place and it passes straight along its original path. When, however, the angle of incidence is small, sin *i* and sin *r* may be taken to be equal to *i* and *r* (measured in circular measure) respectively and, therefore, we have

$$n=i/r, \text{ or, } i=nr.$$

6.8. APPARENT DEPTH OF A TRANSPARENT MEDIUM

Let *O* (Fig. 6.6) represent a *point object*, placed on the under surface of a parallel-sided slab of some refracting medium, such as glass. Then, a ray *OC*, incident normally on the upper face, will not suffer any refraction and so will travel along the same path *OC*. Another ray *OA*, making an angle *OAN* with the normal to the surface at *A*, will be bent along *AB*, since it is travelling from the *denser to the rarer medium*. Produce *BA* backwards to meet the ray *OC* at *O'*. Then *O'* is the *virtual* image of *O*.

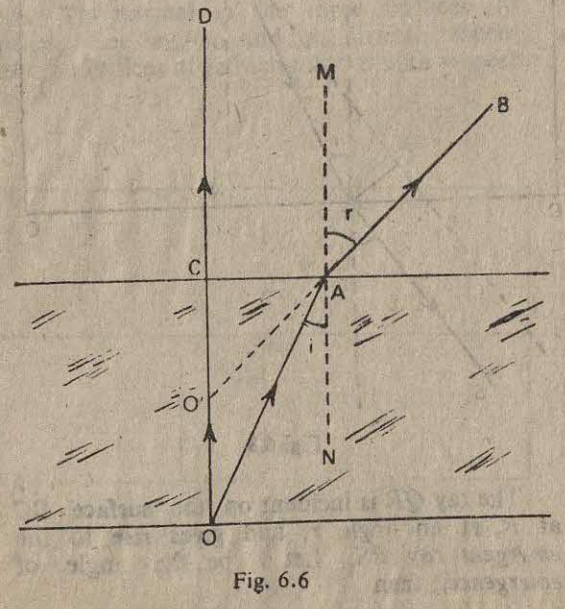


Fig. 6.6

Let *n* be the refractive index of glass. Then, since *OA* is passing from a denser to a rarer medium, we have

$$\frac{1}{n}=\frac{\sin OAN}{\sin MAB}=\frac{\sin AOC}{\sin AO'C}=\frac{AO'}{AO}$$

Since the size of the pupil is small, the rays must emerge near to *C*, in order they may enter the eye and, for this purpose the point *A* may be supposed to be very near *C*.

Hence, $AO'=CO'$ and $AO=CO$ (approximately)

$$\therefore \quad \frac{1}{n}=\frac{AO'}{AO}=\frac{O'C}{OC}, \text{ or } O'C=\frac{OC}{n}.$$

If *t* be the thickness of the glass slab, the distance of *O'* from its surface, say, *v*, is given by $v=t/n$.

Since $n>1$, $v<t$, and *the object seems to be raised up. This explains why a pond of water appears to be shallower than it really is.*

For water, *n* is 4/3 ; hence if the depth of the pond is *one metre*, it appears to be only 75 cm.

If follows from the above that, if the apparent position of the object be known, the refractive index of the medium can be calculated. For, clearly,

$$n=\frac{\textit{real depth}}{\textit{apparent depth}}.$$

6.9. DETERMINATION OF INDEX OF REFRACTION BY THE MICROSCOPE METHOD

1. **Refractive Index of Glass.** Make a pencil mark on a paper and focus on it a microscope, capable of moving vertically up and down, by means of a screw, and read its position on the scale. Now, place a glass slab on the mark and again focus the microscope on the virtual image of the mark, as seen through the glass slab. The distance *PP'*, (Fig. 6.7), through which the microscope has to be raised, gives the distance *OO'* in (Fig. 6.6),

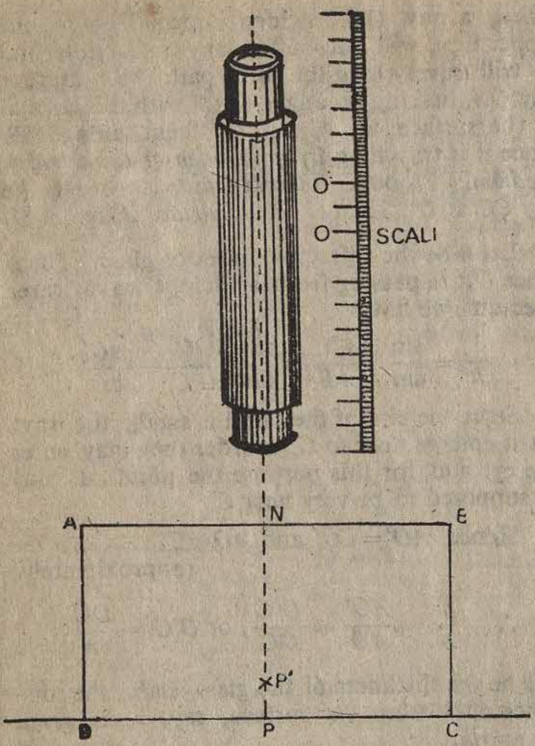


Fig. 6.7

by which the image appears to be raised up. Next, focus the microscope on a scratch, made on the upper surface of the slab and again read its position on the scale. The difference between the first and the last readings gives the *real thickness* of the glass slab. From these two observations, the apparent thickness can be found out by subtracting *PP'* from the real thickness, and then *n* is easily calculated from the relation

$$n = \frac{\textit{real thickness}}{\textit{apparent thickness}} .$$

2. **Refractive Index of a Liquid.** Take a glass vessel and focus the microscope on a mark at its bottom. Then, pour in the liquid and re-focus the microscope on the mark. Next, sprinkle a little lycopodium powder on the surface of the liquid and focus the microscope on a particle of it. Then, the calculations are made in the same way as for glass.

The refractive indices of a few common substances, with respect to air, are given below :

Water	... 1·33	Quartz	... 1·55
Turpentine oil	... 1·47	Crown glass	... 1·52
Linseed oil	... 1·48	Flint glass	... 1·67
Alcohol	... 1·337	Ruby	... 1·71
Ice	... 1·31	Diamond	... 2·47
Benzene	... 1·50	Air	... 1·00

6.10. REFRACTION THROUGH A PARALLEL-SIDED PLATE

Let *AB* and *DC* be the sections of the two parallel sides of a plate of glass or any other transparent medium, of refractive index *n*. (Fig. 6.8). The surfaces, of which *AB* and *DC* are the sections, are supposed to be perpendicular to the plane of the paper. A ray *PQ*, incident at the point *Q* at an angle *i*, gives rise to a refracted ray, *QR*. Let *r* be the angle of refraction at *Q*, then

$$\frac{\sin i}{\sin r} = {}^a n_g$$

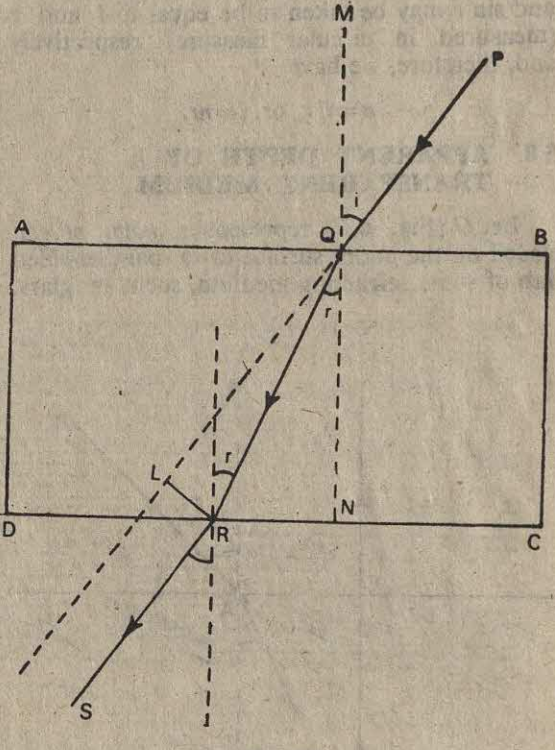


Fig. 6.8

The ray *QR* is incident on the surface *DC* at *R*, at an angle *r*, and gives rise to the *emergent ray RS*. Let *i'* be the angle of *emergence* ; then

$$\frac{\sin r}{\sin i'} = \frac{1}{{}^{a}n_{g}}$$

or, $\dfrac{\sin i}{\sin r} = \dfrac{\sin i'}{\sin r}$, where $\sin i = \sin i'$

or $\qquad i = i'$.

Thus, the emergent ray RS is parallel to the incident ray PQ.

The ray *RS* is, however, *displaced laterally*, with respect to the incident ray *PQ*. Produce *PQ* and from *R* draw *RL*, perpendicular in *PQ* produced ; then, *RL* gives the *lateral displacement*. Let *t* be the thickness of the glass plate ; then $QN/QR = \cos r$.

or $\qquad QR = QN/\cos r = QN \sec r = t \sec r$

But $\quad RL = QR \sin RQL = QR \sin (i - r)$

So that $\quad RL = t \sec r \sin (i - r)$

Thus, the lateral displacement, for a given angle of incidence, is proportional to thickness of the plate. Hence, by making *t* sufficiently small, the lateral displacement can be made as small as we please.

6.11. REFRACTION THROUGH A COMPOUND PLATE

Let a ray *PQ* (Fig. 6.9), pass from a medium *A* through two parallel slabs, of media *B* and *C*, cut into the same medium *A*. For simplicity, suppose the medium *A* to be, *air* medium *B*, to be *water*, and medium *C*, to be *glass*. The normal to the three surfaces are parallel. Let ${}^{A}n_{B}$ ${}^{B}n_{C}$ and ${}^{C}n_{A}$ denote respectively the indices of refraction of *B* with respect to *A*, of *C* with respect to *B* and of *A* with respect to *C*. Now, experiment shows that the emergent ray *ST* is always parallel to the incident ray *PQ* *provided the surfaces of the slabs are parallel and the medium above and below the compound plate is the same*, therefore we have

$${}^{A}n_{B} = \frac{\sin i}{\sin r_1},\ {}^{B}n_{C} = \frac{\sin r_1}{\sin r_2} \text{ and } {}^{C}n_{A} = \frac{\sin r_2}{\sin i}.$$

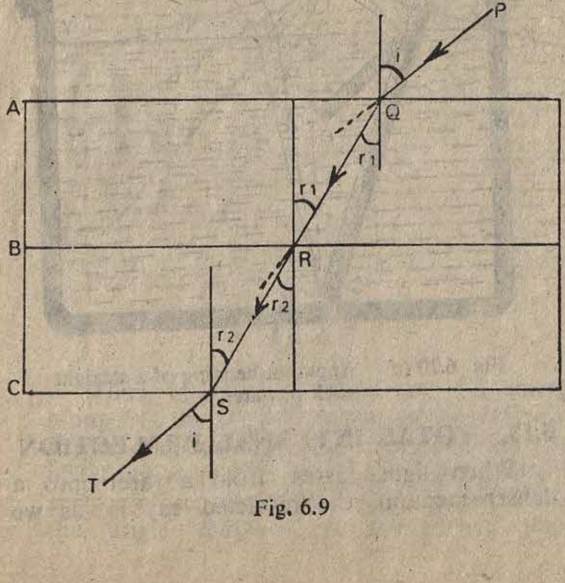


Fig. 6.9

Multiplying the three equations together, we get

$${}^{A}n_{B} \times {}^{B}n_{C} \times {}^{C}n_{A} = 1$$

$$\therefore \qquad {}^{B}n_{C} = \frac{1}{{}^{A}n_{B} \times {}^{C}n_{A}}$$

But $\qquad {}^{C}n_{A} = \dfrac{1}{{}^{A}n_{C}}$

$$\therefore \qquad {}^{B}n_{C} = \frac{{}^{A}n_{C}}{{}^{A}n_{B}}.$$

Hence the refractive index of a medium C with respect to another medium B is equal to the refractive index of C divided by the refractive index of B.

Thus, the refractive index of glass with respect to water

$$= \frac{\text{refractive index of glass}}{\text{refractive index of water}}$$

$$= \frac{3}{2} \times \frac{3}{4} = \frac{9}{8}$$

6.12. SOME FACTS EXPLAINED BY REFRACTION OF LIGHT

(1) Why the Sun appears to be larger in size at Sun-rise or Sun-set than at Noon. Since the atmosphere extends up to a distance of about 500 km above the surface of the earth and the sun is viewed through the layers of air of different densities, it appears a little larger than if there had been no atmosphere. This increase in size varies with the thickness of the air. When the sun is nearer the horizon, the thickness of the air through which light has to pass is the maximum and so it appears to be of a larger size than at noon, when the light has to pass through the minimum thickness of air [Fig. 6.10(*a*)].

(2) **Why water appears shallower than it really is**. Suppose a coin was placed at the bottom of water in a bucket and you were asked to pick it up. You would dip your

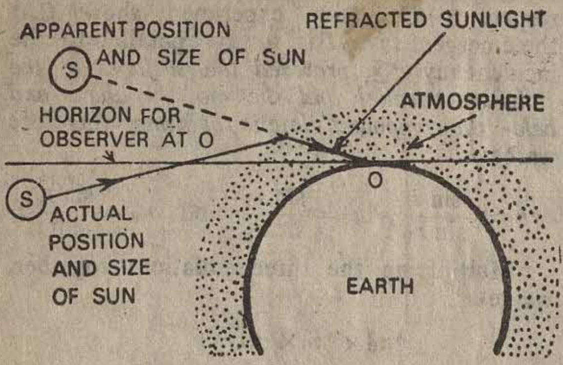


Fig. 6.10 (*a*).

hand inside the bucket, thinking the water was quite shallow, but you would find, to your surprise, that though the sleeve of your shirt was deep in water, your hand had not yet reached the coin. How is this explained ?

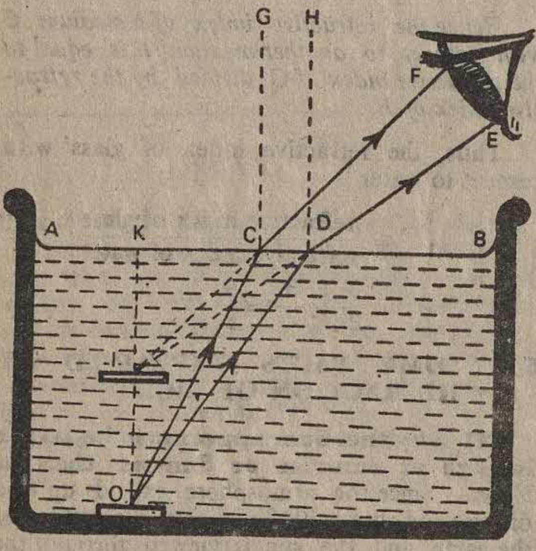


Fig. 6.10 (*b*). Deep water appears shallow.

Consider Fig. 6.10(*b*). Suppose *O* is the coin at the bottom of water whose surface is *AB*. You have learnt previously that to find the position of an object you have to draw two rays from the object and find out what happens to them. Now let us draw two rays *OC* and *OD*. Since the rays are going from a denser medium (water) to a less dense medium (air), the ray *OC* is bent *away* from the normal *CG* in the direction *CF*, and the ray *OD* is bent in the direction *DE*. These rays diverge, and an eye placed at *FE* will collect the rays. It will appear to the eye that the rays are coming from the point *I* where these rays meet when they are produced backwards. The point *I*, therefore, is the *virtual image* of the object (coin) *O*. Since *AB* is the surface of the water, the image *I* is nearer the surface than the object *O*.

Join *OI* and produce it to meet the surface *AB* at *K*. Then *OK* is called the *real depth* of the coin and *IK* the *apparent depth*. The apparent depth is *less* than the real depth, *i.e.*, the water appears shallower than it really is.

(3) Why a straight stick appears bent in water. Let us consider Fig. 6.10(*c*) *ABC* is a straight stick or ruler placed in water in a slanting position. The surface of the water is *XY* and the eye is placed in position E. The eye would see the portion *AB* by direct rays through air as shown by the cones of rays, *A*E and *B*E, but the portion *BC* is seen through water. As explained above in the case of the coin, end *C* of the stick will appear to the eye to be at *D* as shown in the diagram. Thus, the eye sees the straight stick *ABC* as a bent stick *ABD*.

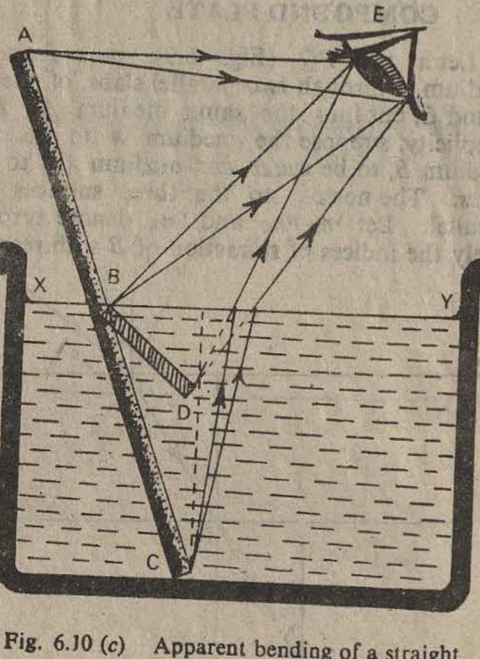


Fig. 6.10 (*c*) Apparent bending of a straight stick in water.

6.13. TOTAL INTERNAL REFLECTION

When light passes from a rarer into a denser medium, the refracted ray is, as we know, bends towards the normal, so that even when the angle of incidence is about 90°, a refracted ray is possible. On the contrary, if the second medium is less refracting than the first, as when light passes from glass into air, the refracted ray is bent away from the normal, so that the angle of refraction is now greater than the angle of incidence. If, therefore, the angle of incidence be gradually increased, the corresponding angle of refraction will also increase, till a limit is reached when the angle of refraction becomes equal to 90° and the refracted ray travels parallel to the surface of separation of the two media. If the angle of incidence is increased still further, there is no refracted ray and the incident ray is reflected back into the denser medium, in accordance with the ordinary laws of reflection. This is known as *total internal reflection.* The angle of incidence at which total reflection *just* occurs, *i.e.*, for which the corresponding angle of refraction is 90°, is called the **critical angle** for the two given media. It is represented by i_c.

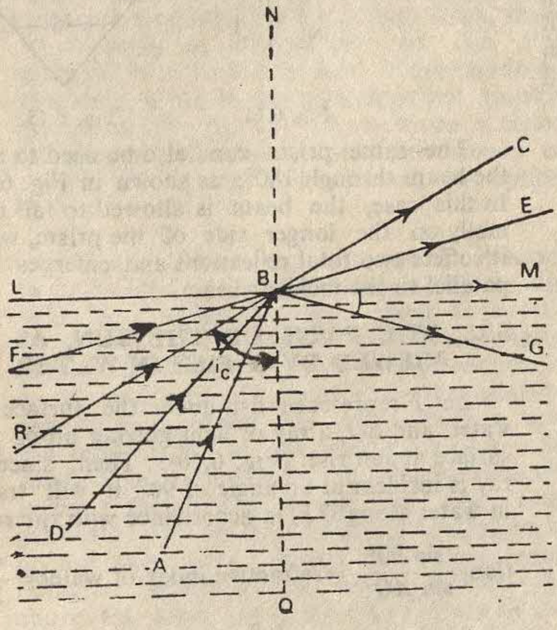


Fig. 6.11.

Thus, in Fig. 6.11, the ray *AB* emerges along *BC*, the ray *DB* emerges along *DE*, while the ray *RB*, for which the corresponding angle of refraction is 90° just grazes along *LM*, the surface of separation of the two media. Hence, the angle $RBQ = i_c$ is the *critical angle.* Evidently, then, the beam *FB is totally* reflected along *BG* according to the ordinary laws of reflection.

Since, for the critical angle *RBQ*, the angle of refraction is 90°, we have

$$\frac{\sin RBQ}{\sin 90°} = \frac{1}{n},$$

where n is the *refractive index of the denser medium* with respect to the rare one.

$$\text{Hence,} \quad \sin i_c = \frac{1}{n},$$

$$\text{for,} \quad \sin 90° = 1$$

or *sine of the critical angle* $= \frac{1}{n}$

Hence we conclude from the above that *whenever a ray of light travelling from a denser into a rare medium, is incident at an angle greater than the critical angle for the two media, the ray is totally reflected back into the same medium.*

Let us find the critical angle for water and air. Since ${}^a n_w$ for water = 1·33, the critical angle $i_c = \sin^{-1}(1\cdot33) = 48°45'$.

Similarly, the critical angle for glass is 41°9′.

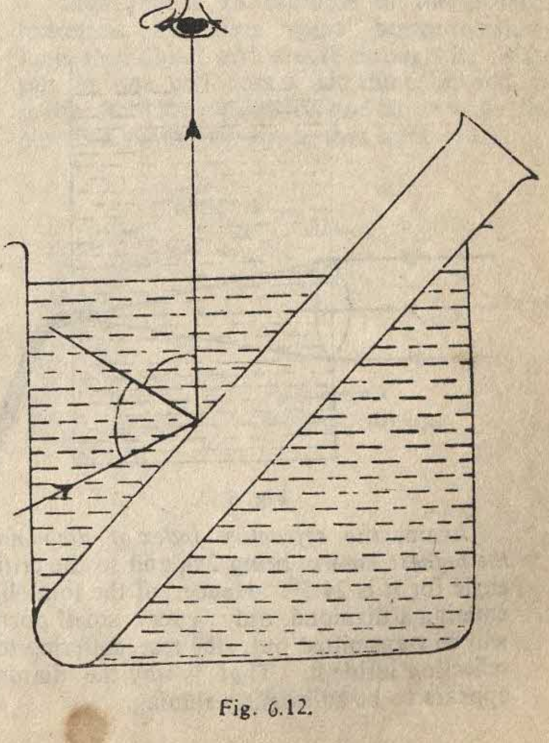


Fig. 6.12.

This at once explains, why an empty test tube held obliquely in a glass beaker, containing water, when looked at from some distance on one side, appears to be shining, as though it were full of mercury. This is so, because the rays of light, incident through water on the side of the tube are totally reflected back, as shown in Fig. 6.12. If the tube is filled with water, it no longer has that appearance.

This phenomenon can be beautifully demonstrated by an experiment, called the *Fountain of fire*.

A rectangular vessel is taken, in one side of which a convex lens L of focal length equal to the breadth of the vessel is fixed (Fig. 6.13). Along the axis of the lens, in the side opposite, is a small hole. A strong parallel beam of light is allowed to fall on the lens and is brought to focus on the hole. The vessel is then filled with water, the hole having been closed by a cork. On removing the cork, a brilliant jet begins to stream out of the hole in the form of a parabola. The angle of incidence on the interior surface of the jet being greater than the critical angle, the beam is reflected from side to side all along the stream and so it appears brilliant. If a red glass be placed in front of the lens, the stream becomes red and it looks as if fire is flowing out of the vessel.

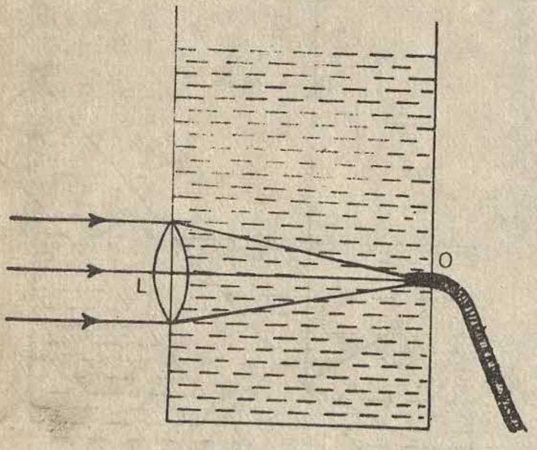


Fig. 6.13.

Again, *the refractive index of diamond is the highest known*, being 2·4, and so the critical angle for it is 24·5°. Hence, of the total light entering a diamond, only a very small portion will be transmitted out, the rest suffering total reflection inside it. That is why the diamond appears to be so brightly shining.

6.14. TOTALLY REFLECTING PRISMS

In Fig. 6.14, ABC represents a section of a right-angled glass prism (90°, 45°, 45°) and LM, a ray incident *normally* on the face AB. It enters the prism undeviated and then falls on the face AC at an angle of 45° which is greater than the critical angle (41°9′) for glass. Consequently, it is *totally reflected* along MN and falls on and emerges out of the face BC, *normally*. Thus, the ray LM is deviated through 90°, *without any loss of intensity*. Such a prism is called a *totally reflecting prism* and is often used, instead of a mirror, for reflecting a beam through 90°.

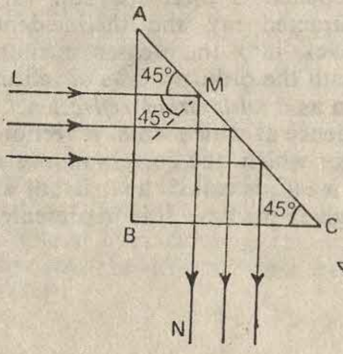


Fig. 6.14

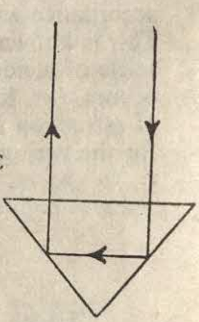


Fig. 6.15.

The same prism can also be used to turn the beam through 180°, as shown in Fig. 6.15. In this case, the beam is allowed to fall normally on the longer side of the prism, when it suffers two total reflections and emerges out parallel to the incident beam.

6.15. THE PATH OF THE SUN, AS VIEWED BY A FISH IN WATER

Let F represent a fish under the surface of water, and SO, a ray of light grazing along the surface at sun rise (Fig. 6.16). Then, sincethe ray is incident at an angle of 90°, it will travel in water along OF, in accordance with the relation

$$\frac{\sin 90^\circ}{\sin AOF}=\text{refractive index of water}=\frac{4}{3},$$

or $\angle AOF=\sin^{-1}\left(\frac{3}{4}\right)=48^\circ\ 36'$.

Hence the fish will see the sun at S', at an angle equal to $(90-48^\circ\ 36')=41^\circ\ 24'$ above the horizon. At sun set also, the sun will appear to subtend the same angle 41° 24′ with the horizon. Thus the path of the sun, as viewed by the fish, is an arc, equal to $48^\circ 36'\times 2=97^\circ\ 12'$.

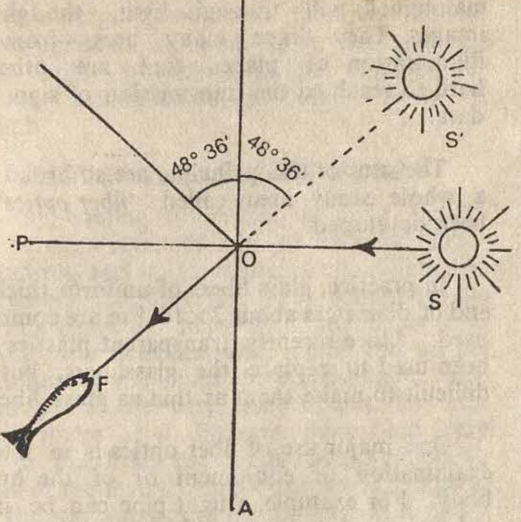


Fig. 6.16.

6.16. OPTICAL ILLUSION

When an object appears to be of a particular form, when looked at from a distance, whereas, in reality, it is *not* of that form, there is obviously an illusion to the eye. For example, if we look at a star, it appears to be twinkling, while, in reality, it does not twinkle (see Art 6·18). Such a phenomenon is called an **optical illusion**: The phenomenon of mirage is a typical example of an optical illusion.

Mirage The *mirage* is an optical illusion, in which inverted images of distant objects are seen, as if reflected from a pond or a lake or sometimes, as if suspended in the atmosphere. The former type of the phenomenon is of most frequent occurrence in hot climates and more especially, in sandy districts, and the latter type, in the colder regions. In sandy deserts, because of the intense heat, the layers of the air, near the surface of the earth, get heated so soon that the density adjustments do not take place ; hence the densities and refractive indices of the layers immediately above the sand are lower than those of the layers higher up. The rays of light from a distant object, after passing through layers, which are gradually less refracting, bend more and more (Fig. 6.17) till they fall on a layer at an angle, greater than the critical angle for it, and get totally reflected. These reflected rays then travel up and undergo a series of refractions, but in a direction opposite to those in the first case ; for, they now pass through layers which are gradually more and more refracting, till they reach the eye of the observer, who sees an image of the object, as though reflected from the surface of a calm lake of water.

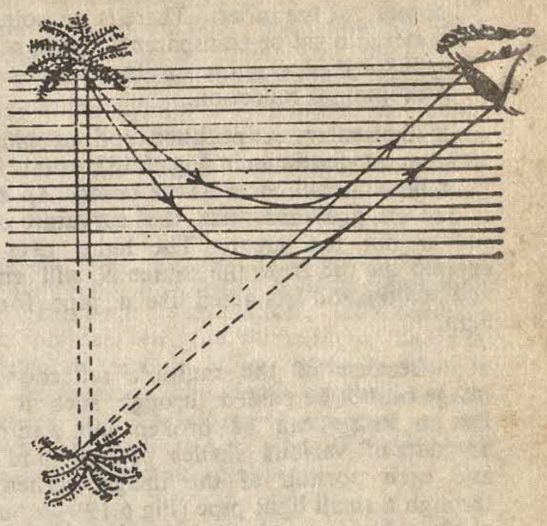


Fig. 6.17 The Mirage.

6.17 THE LIGHT PIPE AND FIBRE OPTICS :

Light pipe is an example of **total internal** reflection. The term "pipe" brings to mind a long, thin object with a hole through it. Water put in one end comes out the other end, no matter how the pipe twists and turns. A light pipe is a similar device, in that light put in one

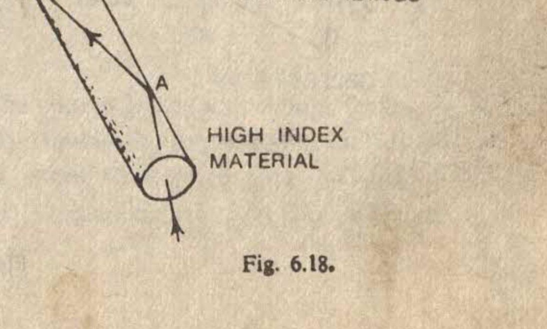


Fig. 6.18.

d comes out the other. There is no hole, but e material must be transparent. The light pipe ends for its operation on the phenomenon otal internal reflection.

If light enters a polished rod of glass or ransparent plastic as in Fig (6.18), total internal reflection will occur at the points *A*, *B*, *C*, d so on, provided that the curvature of the rod is not too great. The light rays that entered the rod from the source *S* will emerge at F, so the rod has acted like a pipe for the light.

Because of the multiple reflections, an image cannot be passed through such a pipe. But an image can be broken into a series of fine dots of various shades of light and dark and each portion of the image is then sent through a small light pipe (Fig 6.19). A bundle f glass fibers, each acting like a light pipe, transmit an image if the arrangement of e emerging fibers is the same as that at the entrance end. A lens is used to cast an image e end of the bundle, and the image is transmitted to the other end. One necessary addition is that each fiber be coated with a material of low index so that the light in one fiber does not cross into adjacent ones at points where there is contact. dles in which the order of the fibers is not maintained will transmit light, though not images. They have many uses, from the illumination of places that are otherwise hard to reach to the transmission of signals or data.

The uses of this principle are so broad that a whole study area called "*fiber optics*" has been developed.

In practice, glass fibers of uniform thickness and of diameters about 2×10^{-6} m are commonly used. More recently, transparent plastics have been used to replace the glassfibers, but it is difficult to make them as thin as glass fibers.

One major use of fiber optics is in internal examination of equipment or of the human body. For example, a light pipe can be inserted into a patient's stomach through the mouth and used to examine the stomach for ulcers. Light that is transmitted down the outer layer of the light pipe's optical fibers is scattered back by the stomach wall and transmitted through the central portion of the fiber bundle to produce an image of the stomach wall. This image can be either observed visually or recorded photographically. Since the fibers are very thin and numerous, excellent details can be achieved in the final image produced.

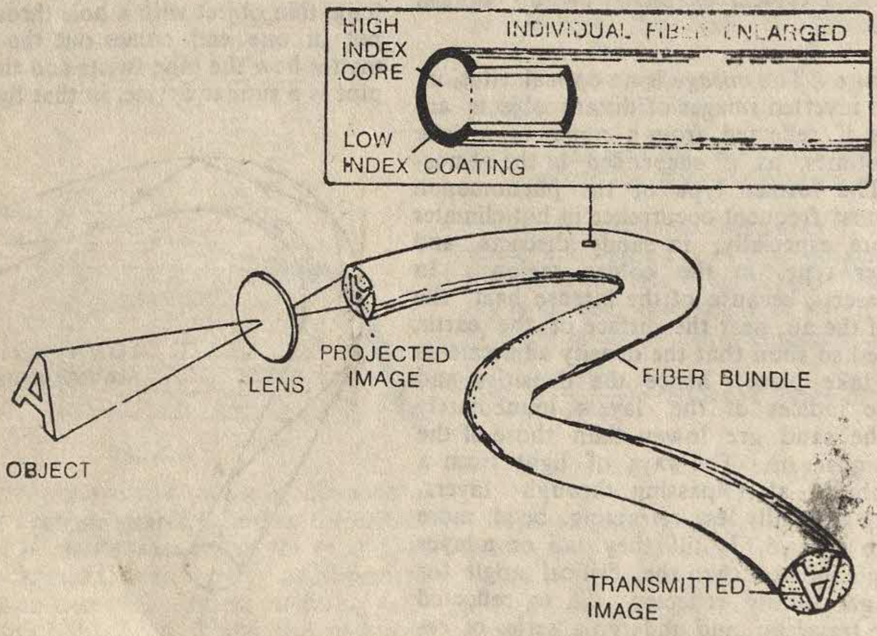


Fig. 6.19.

Such light pipes can also be used to transmit high intensity laser light inside the body for use in surgery and cancer therapy. The use of fiber optics in medicine again demonstrates that a simple physical principle can have far reaching consequences in other fields of research.

6.18. THE TWINKLING OF STARS

A ray, coming from a star, at night has to pass through layers of air, of different refractive indices, and is, therefore, bent differently, till it meets the observer's eye, which sees the star in a particular position. But, because of the wind, the densities, and hence the refractive indices of the layers go on changing continuously, so the very next instant the star appears to be at a different place, but very near to the first, the change in the refractive indices of the layers being quite small. Therefore, the star appears to be moving in a small area,—hence its twinkling. The planets being nearer, the amount of light received from them is greater and so the variation in their brightness is not appreciable. That is why they do not appear to twinkle.

Similarly, the apparently higher altitude of a star is an optical illusion. For, the rays from the star *S* (Fig. 6.20), are bent more and more towards the normal, since they have to pass through layers of increasing density, due to the atmospheric pressure, till they reach the observer's eye. If the last parts of the rays are produced backwards, they will appear to come not from *S* but from *S′* which is higher than *S*. Rays entering the atmosphere are lifted by atmospheric refraction by 0·5°. This is very nearly equal to the angle subtended by the sun's disc so that when the sun appears to be just above the horizontal sunrise or sunset, it is actually just below it. Again since the sun requires about two minutes to move a disiance equal to its own diameter, the day at the equator is lengthened by about two minutes both at sunrise and sunset. Hence the sun rises about 2 *minutes earlier* and sets about 2 *minutes later*, the day thus becoming longer by about four minutes.

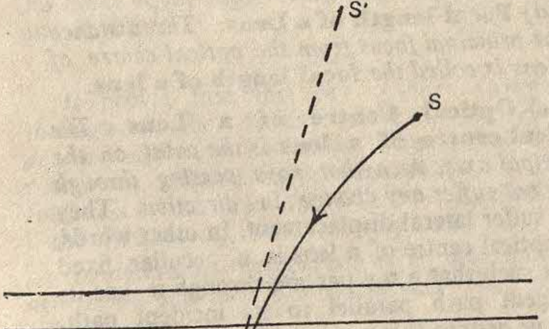


Fig. 6.20.

Again, since the sun is viewed through atmospheric air, it appears a little larger than if there had been no atmosphere. This increase in size increases with the thickness of the air, as explained already. For, when the sun is near the horizon, the depth of the air is the maximum and, therefore, it appears to be larger in size than at noon, when the rays pass through the minimum thickness.

6.19. LENSES.

A lens may be defined as a portion of transport medium bounded by two curved surfaces or by one curved surface and the other plane surface.

The curved surfaces are generally spherical and the medium mostly employed is glass. Such lenses are called spherical lenses.

If one of the bounding curved surfaces is cylindrical the lens is called a cylindrical lens.

It is usual to divide lenses into two classes :

(*i*) **Convex or Convergent lenses, and**

(*ii*) **Concave or Divergent lenses.**

(*i*) **Convex or Converging Lenses :**

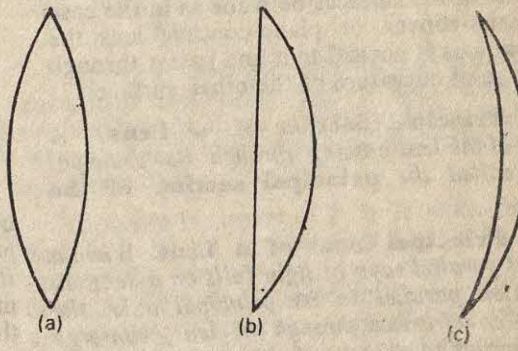


Fig. 6.2.1

The convex lenses are of three forms :

(1) Double Convex lens [Fig. 6.21 (*a*)].

(2) Plano Convex lens [Fig. 6.21 (*b*)].

(3) Concave-Convex lens [Fig. 6.21 (*c*)].

The distinguishing characteristic of a convex lens is that it is *thicker* at the centre than at the edges.

(*ii*) **Concave or Divergent Lenses.** The concave lenses are likewise of three forms :

(*a*) Double concave lens [Fig. 6.22 (*a*)].

(*b*) Plano-concave lens [Fig. 6.22 (*b*)].

(*c*) Convex-concave lens [Fig. 6.22 (*c*)].

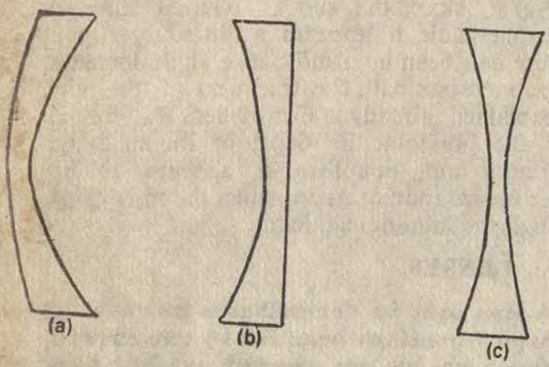


Fig. 6.22.

The distinguishing characteristic of a concave lens is that *it is thinner at the centre than at the edges.*

6 . DEFINITIONS OF TERMS RELATING TO LENSES.

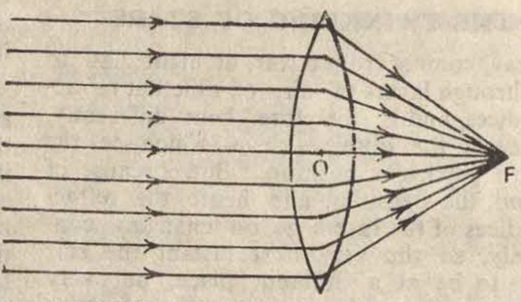
(*a*) **Principal Axis of a Lens.** *The straight line passing through the centres of curvature of the surfaces of the lens is called the* **principal axis of the lens.**

If one of the surfaces be plane as in the case of a plano-convex or plano-concave lens, the principal axis is normal to it and passes through the centre of curvature of the other surface.

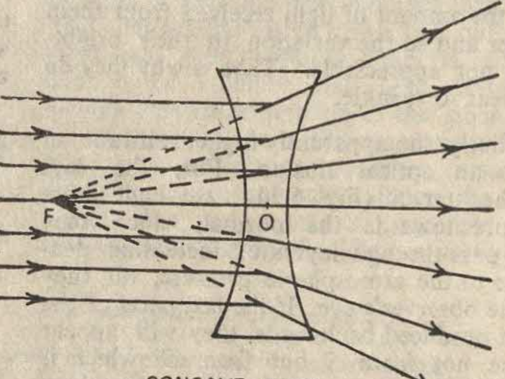
(*b*) **Principal Section of a Lens.** *A section of the lens passing through its principal axis is called the* **principal section of the lens.**

(*c*) **Principal Focus of a Lens.** *When a beam of parallel rays of light falls on a lens in a direction parallel to its principal axis, the rays, after refraction through the lens, converge to or appear to diverge from a point on the principal axis. This point is called* **principal focus** *of the lens.*

In the case of a convex lens, the beam of light parallel to its principal axis is made to converge to a point *F on the other side* of the lens as shown in Fig. 6.23 (*i*) whereas in the case of a concave lens, the beam of light parallel to its principal axis appears to diverge from a point *F on the same side of the lens* as the incident light as shown in Fig. 6.23 (*ii*).



CONVEX LENS
(i)



CONCAVE LENS
(ii)

Fig. 6.23.

(*d*) **Focal length of a Lens.** *The distance of the principal focus from the optical centre of the lens is called the* **focal length of a lens.**

(*e*) **Optical Centre of a Lens.** *The* **optical centre of a lens** *is the point on the principal axis, such that rays passing through it do not suffer any change in direction.* They may suffer lateral displacement. In other words, the optical centre of a lens is a peculiar fixed point such that a ray passing through it has its emergent path parallel to its incident path. *Let us deduce this result geometrically.

Let C_1 and C_2 be the centres of curvature of the spherical surfaces of a double convex lens $L_1AL_2BL_1$ (Fig. 6.24). Draw any radius C_1R of the spherical surface L_1BL_2. Draw the radius C_2Q of the other spherical surface such that $C_2Q \parallel C_1R$. Clearly, C_1R and C_2Q are normals to the surfaces L_1BL_2 and L_1AL_2 at points R and Q respectively.

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* For further knowledge only.

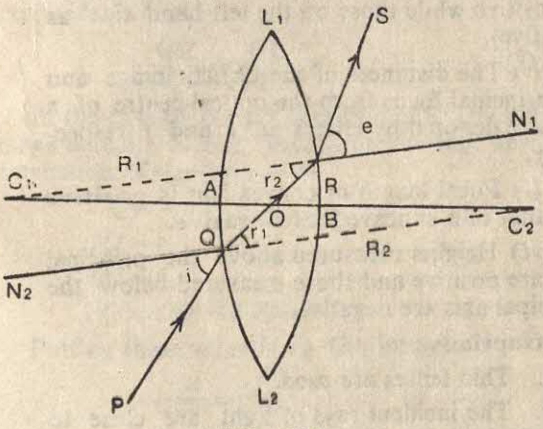


Fig. 6.24.

Join RQ cutting the principal axis, C_1C_2 at *O the optical centre of* the lens. Let QR represent the path of light ray $PQRS$ through the lens. Then,

$$\therefore \quad C_2Q \parallel C_1R \qquad \text{[by construction]}$$

$$\therefore \quad \angle C_2QR = \angle C_1RQ$$

$$\text{or} \quad \angle r_1 = \angle r_2$$

Further, $\because \quad \dfrac{\sin i}{\sin r_1} = n = \dfrac{\sin e}{\sin r_2}$

and since we have proved just now that $\angle r_1 = \angle r_2$,

$$\angle i = \angle e$$

i.e, the incident ray PQ and the emergent ray RS make equal angles with the normals at Q and R. Thus,

$$PQ \parallel RS$$

It proves that the ray $PQRS$ passing through O, the optical centre of the lens, *does not suffer any deviation*. The lateral displacement suffered by it depends upon the thickness of the lens and will be inapplicable if the thickness of the lens is very small.

To determine the position of O, the optical centre, we find that Δs OC_1R and OC_2Q are similar. Hence,

$$\frac{C_1O}{C_2O} = \frac{C_1R}{C_2Q}$$

$$\frac{C_1O}{C_2O} = \frac{R_1}{R_2}$$

which shows that O, the optical centre divides the line joining C_1 and C_2, the centres of curvature of the spherical surfaces of the lens, internally in the ratio of their radii. It is thus a fixed point for a given lens.

In the case of a double convex or double concave lens having spherical surfaces of equal radii ($R_1 = R_2$), the optical centre coincides with the geometrical centre.

(*f*) **Secondary axis of the Lens**. Evidently the principal axis defined in (*a*) above passes through the optical centre. Any straight line other than the principal axis passing through the optical centre is called the secondary axis of the lens.

6.21. POWER OF A LENS.

It is the degree to which a lens converges or diverges the rays of light. It is measured as reciprocal of the focal length of a lens expressed in *metres*. Thus.

$$\text{Power of a lens } (p) = \frac{1}{f\,\text{(metres)}}$$

It is expressed in **dioptre (D)**.

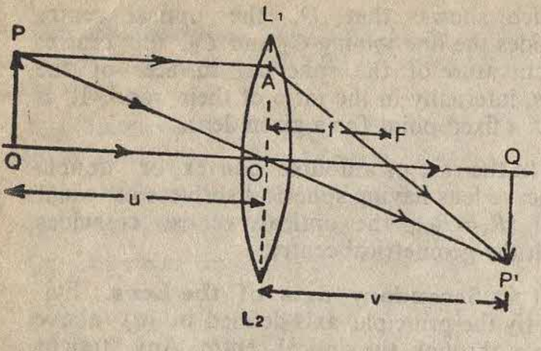
Suppose there is a convex lens whose focal length is 25 cm=0·25 m, its power will be $p = \dfrac{1}{0{\cdot}25} = 4D$. A concave lens of focal length $-$20 cm$=-0{\cdot}50$ m will have,

$$\text{Power } p = \frac{1}{-0{\cdot}20} = -5D$$

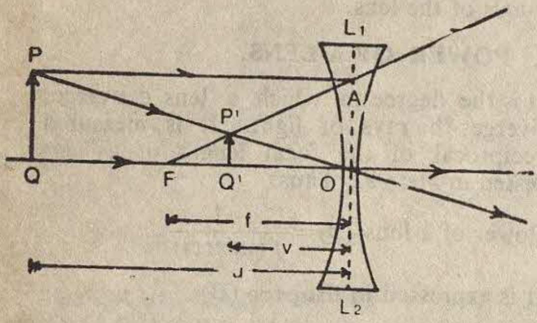
6.22. FORMATION OF AN IMAGE BY A LENS

Let PQ be an object placed on the principal axis of lens L_1L_2 (Fig. 6.25). Regarding the object to be made up of a large number of points let us first determine the position of the image of the point P.

To locate the image of P, it is sufficient to find the point of intersection, after refraction through the lens, of any two rays originally diverging from P. In selection these two rays, we may bear in mind the properties of (*i*) the optical centre and (*ii*) the principal focus of a lens (Art. 6.20). Thus consider a ray PA parallel to the principal axis of the lens. After refraction in the case of a convex lens, it will *pass through the principal focus F* whereas in the case of a concave lens it appear to diverge from F. Another ray PO passing through the



Convex lens



Concave lens

Fig. 6.25.

optical centre, *O*, does not suffer any deviation and hence goes straight. The inter-section *P′* these two rays is the image of *P*. Similarly image of every other point can be found. e collection of these image points. *P′Q′*, is image of the object *PQ*.

If the ***point of intersection P is real***, [Fig. 6.25 (*i*)], ***the image will be real***, **inverted and on the other side of the lens.**

On the other hand, if the rays merely appear to intersect and do not actually intersect, ***i.e., the intersection is virtual*** **[Fig. 6.25 (*ii*)],** ***the image is virtual, erect*** **and on the same side of the lens on which the object lies.**

6.23. LENS FORMULA

The **new sign convention** to be used in proving the lens formula is as follows :

Sign Convention :

(*i*) Distances are measured from the optical centre of a lens.

(*ii*) Light rays will be taken to be travelling from the left to right.

(*iii*) Distances measured in the same direction as that of incident light are taken as **positive** and the distances measured against the direction of incident light are taken as **negative.**

(Accordingly distances on the right hand side of the optical centre of a lens will be taken as positive while those on the left hand side as negative).

(*iv*) The distances of the object, image and the principal focus from the optical centre of a lens are denoted by letters *u*, *v* and *f* respectively.

(*v*) Focal length of convex lens is **positive** and that of a concave lens **negative.**

(*vi*) Heights measured above the principal **axis** are positive and those measured below the principal axis are negative.

Assumptions :

1. Thin lenses are used.
2. The incident rays of light are close to the principal axis of the lens.

We have seen in **Art.** 6.22 that *P′Q′* is the image of the object *PQ* placed on the principal axis of a lens L_1L_2 (Fig. 6.26).

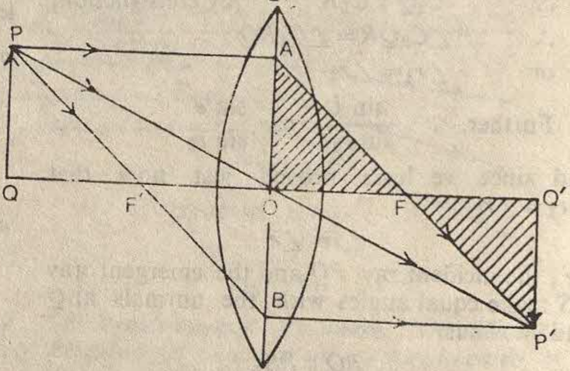


Fig. 6.26

The right-angled △s *OPQ* and *OP′Q′* are similar as ∠*POQ*=∠*P′OQ′* (being vertically opposite angles). Thus,

$$\frac{PQ}{P'O'}=\frac{OQ}{OQ'}$$

Since, *PQ*=*AO*, therefore the above relation may be written as

$$=\frac{AO}{P'Q'}=\frac{OQ}{OQ'} \qquad \ldots(1)$$

The right angled Δs AOF and $P'Q'F$ are also similar. Hence,

$$\frac{AO}{P'Q'}=\frac{OF}{FO'} \qquad ...(2)$$

Since the left hand sides of the *eqs.* (1) and (2) are equal, therefore equating their right hand sides we get

$$\frac{OQ}{OQ'}=\frac{OF}{FO'} \qquad ...(3)$$

In the case of convex lens [Fig. 6.25 (*i*)] the image is real. Hence, according to the new convention of signs, we have

$$OQ=-u$$
$$OQ'=v$$
$$OF=f$$
$$FQ'=OQ'-OF=v-f$$

Putting these value in *eq.* (3), we get

$$\frac{-u}{v}=\frac{f}{v-f}$$

$$\therefore \quad -uv+uf=vf$$

or $$-uv=vf-uf$$

Dividing both sides by uvf, we get

$$-\frac{1}{f}=\frac{1}{u}-\frac{1}{v}$$

or $$\boxed{\frac{1}{v}-\frac{1}{u}=\frac{1}{f}} \qquad ...(4)$$

In the case of concave lens [Fig. 6.25 (*ii*)] the image is *virtual*. Hence, according to the new convention of signs, we have

$$OQ=-u$$
$$OQ'=-v$$
$$OF=-f$$
$$FQ'=OF-OQ'=-f-(-v)=v-f$$

Putting these values in *eq.* (3), we get

$$\frac{-u}{-v}=\frac{-f}{v-f}$$

$$\therefore \quad -uv+uf=vf$$

or $$-uv=vf-uf$$

Dividing both sides, by uvf, we get

$$-\frac{1}{f}=\frac{1}{u}-\frac{1}{v}$$

or $$\boxed{\frac{1}{v}-\frac{1}{u}=\frac{1}{f}} \qquad ...(4)$$

Thus, we get the same formula for both types of the lenses, convex and concave.

Conjugate Foci :

Any two points Q and Q' lying on the principal axis of the convex lens connected by the relation

$$\boxed{\frac{1}{v}-\frac{1}{u}=\frac{1}{f}}$$

are called **conjugate foci.** In other words, if the object is placed at Q, the image will be at Q' and *vice versa.*

6.24. LINEAR MAGNIFICATION PRODUCED BY A LENS

It is evident from Fig. 6.25 or Fig. 6.26 that Δs $OP'Q'$ and OPQ are similar. Hence,

$$\frac{P'O'}{PQ}=\frac{OQ'}{OQ}$$

or $$\frac{\text{Size of the image}}{\text{Size of the object}}=\frac{I}{O}=\frac{v}{u} \quad \text{[C.T.M.]}$$

Thus linear magnification produced by a lens is the ratio of the distance of the image to that of the object from this lens.

The ratio $\frac{v}{u}$ will be *positive* in the case of a virtual image and *negative* in the case of a real image.

It can be easily prove that for a lens,

$$\frac{I}{O}=\frac{v}{u}=\frac{f}{u+f}=\frac{f-v}{f}$$

6.25. POSITION, NATURE AND MAGNIFICATION PRODUCED BY A CONVEX LENS AND A CONCAVE LENS

(1) **Convex lens** (*i*) Let us start with the **object at infinity,** so that the rays from it, incident on the lens, are all parallel to each other, [Fig. 6.27 (*i*)(*a*)].

If the rays be parallel to the axis (case *a*), they all meet in F, the *focus* of the lens, giving a *point-image* of the object at F. But if they are not parallel to the axis, [Fig. 6.27 (*i*) (*b*)], we get an *extremely diminished image* $A'B'$ of the object, at F. In either case, because the rays actually cross each other at *F* the image is *real* and *inverted*.

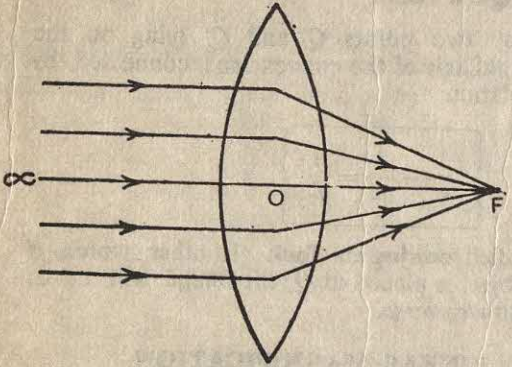


Fig 6.27 (*i*) (*a*)

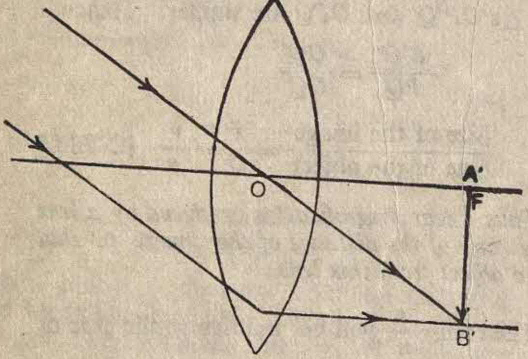


Fig. 6.27 (*i*) (*b*)

Thus in this case *the image lies at F,* and is *real, inverted* and *extremely diminished in size—almost a point-image.*

Figures 6.27 (*ii*) to Fig. 6.27 (*vi*) show the different cases, when the object *AB*, placed at right-angles to the axis of the lens is gradually brought from beyond $2F$ or twice the focal length of the lens to very near the lens, where $A'B'$ is the image of the object formed.

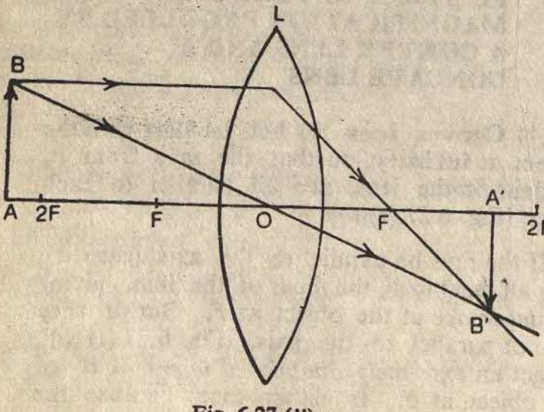


Fig 6.27 (*ii*)

(2) Fig. 6.27 (*ii*) shows the **object beyond 2F**, when *its image* is *formed between F and 2F*, (on the other side), and is *real, inverted* and *diminished in size.*

(3) Fig. 6.27 (*iii*) shows the **object at 2F**, when its *image is also formed at* 2F and is *real, inverted* and of the *same size as the object.*

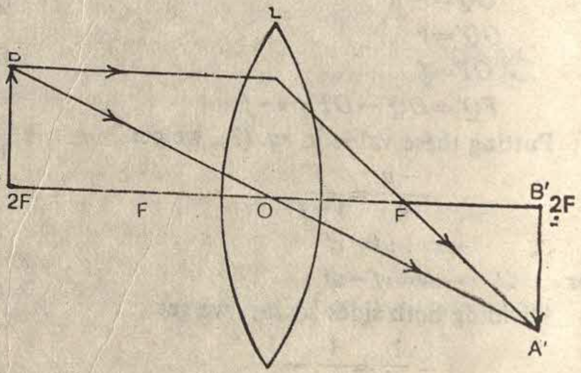


Fig. 6.27 (*iii*)

(4) Fig. 6.27 (*iv*) shows the object **between F and 2F,** *the image being formed beyond 2F and being real, inverted* and *magnified.*

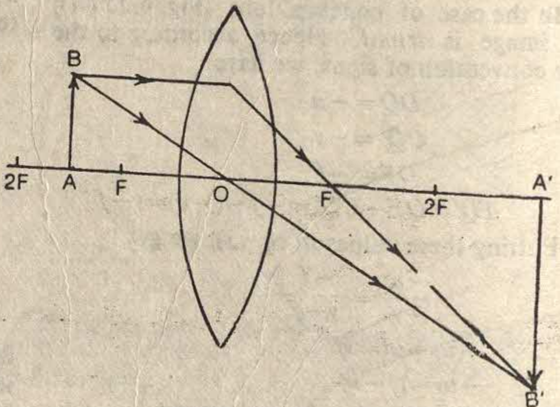


Fig. 6.27 (*iv*)

(5) Fig. 6.27 (*v*) shows the **object at F,** *the image in this case being formed at infinity, and being real, inverted* and *highly magnified.*

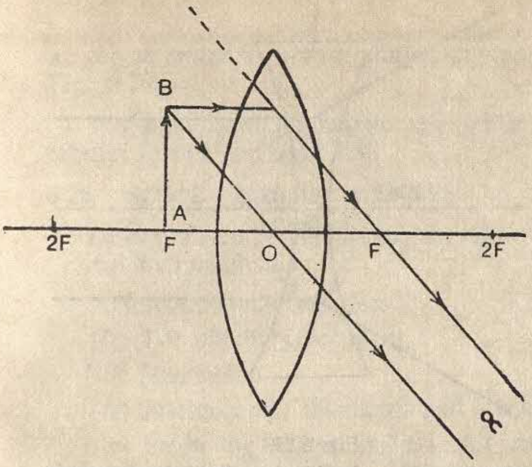


Fig. 6.27 (*v*)

(6) Fig. 6.27. (*iv*) shows the object **within the focus**, or *between the optical centre of the lens and F, the image now being formed on the same side as the object, and virtual, erect* and *magnified.* The lens, in this case, acts as a *magnifying glass.*

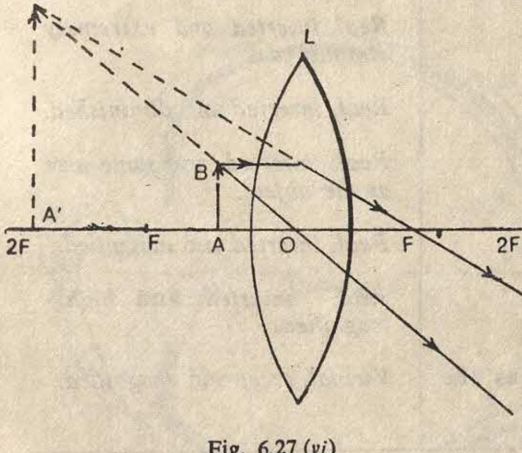


Fig. 6.27 (*vi*)

(2) **Concave lens**. (*i*) Here also, let us start with the **object at infinity,** so that the incident rays are parallel to each other. If they be parallel to the principal axis (Fig. 6.28 (*a*)], they diverge on passing through the lens as though they were proceeding from *F*, the *focus* of the lens, on the same side as the object and a *point-image* thus appears to be formed at *F*. But if the rays be not parallel to the principal axis, [Fig. 6.28 (*b*)], they diverge on refraction through the lens, so as to form an extremely diminished virtual image at *F*. In either case, therefore, the *image lies at F and is virtual, erect and extremely diminished.*

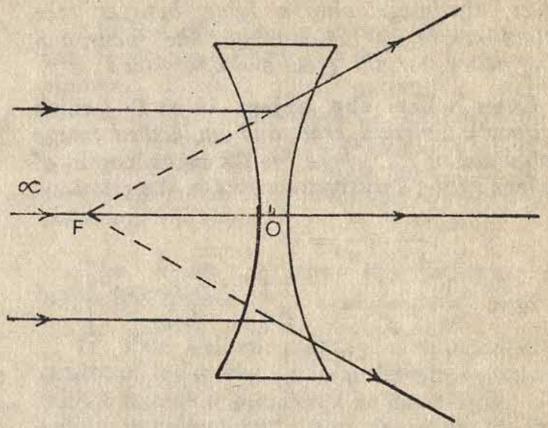


Fig. 6.28 (*i*)

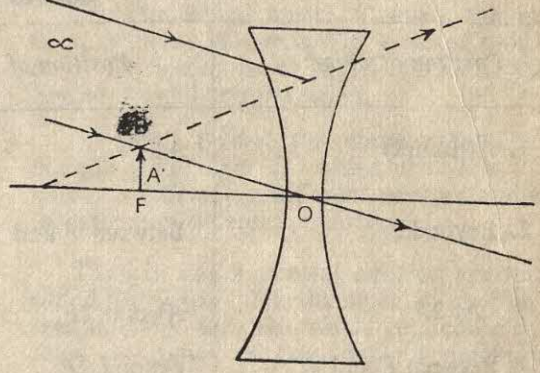


Fig. 6.28 (*ii*)

(*ii*) Fig. 6.28 (*c*) shows the case of an *object* (*AB*) **beyond 2F**, when, a *virtual, erect and diminished image* (*A'B'*) *of the object is*

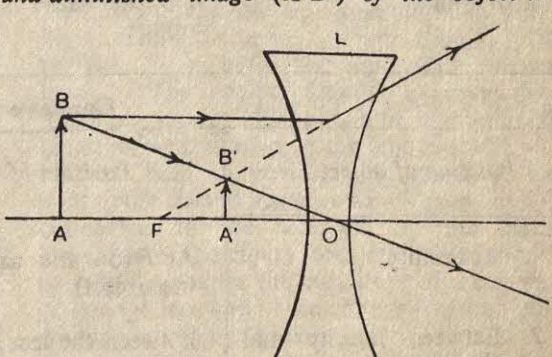


Fig. 6.28 (*iii*)

obtained between the optical centre of the lens and its focus.

The same happens in all other of a real object, the *image always lying between the optical centre of the lens and the focus, and being always virtual, erect and diminished.*

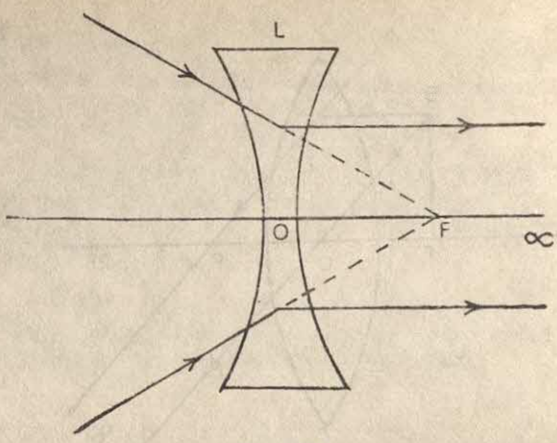


Fig. 6.29

Even when the object is at F (which is *virtual*), a *virtual, erect and diminished image is obtained at f/2, where f* is the focal length of the lens ; for ; substituting $u=f$ in the relation

$$\frac{1}{v}-\frac{1}{u}=\frac{1}{f}$$

we have $\frac{1}{v}+\frac{1}{f}=-\frac{1}{f}\left[\because f \text{ is } -\text{ve here.}\right]$

or, $\frac{1}{v}=-\frac{1}{f}-\frac{1}{f}=-\frac{2}{f}$,

whence, $v=-\frac{f}{2}$, the $-ve$ sign of v indicating that the image is *virtual* as it is on the same side as the object.

It is only when a converging beam, appearing to meet at F, is incident on the lens that

Convex Lens

Position of object	*Position of image*	*Nature and size*
1. At infinity	At *F*	*Real, inverted and extremely diminished.*
2. Beyond 2*F*	Between *F* and 2*F*	*Real, inverted* and *diminished.*
3. At 2*F*	Also at 2*F*	*Real, inverted* and *same size as the object.*
4. Between *F* and 2*F*	Beyond 2*F*	*Real, inverted* and *magnified.*
5. At *F*	At infinity	*Real, inverted* and *highly magnified.*
6. Within *F*	On the same side as the object.	*Virtual, erect* and *magnified.*

Concave Lens

Position of object	*Position of image*	*Nature and size*
1. At infinity	At *F* (on the same side as the object)	*Virtual, erect and extremely diminished.*
2. Between infinity and the lens.	Between the lens and *F*	*Virtual, erect* and *diminished.*

we get an image formed at infinity, as shown in Fig. 6.29.

We may thus summarise the result in a tabular form as on page 170.

6.26. SOME USES OF LENSES

Lenses are used very widely in almost all optical instruments *e.g.*

(*i*) As a magnifying glass

(*ii*) The photographic glass

(*iii*) Spectacles

(*iv*) Microscopes, telescopes and binoculars

(*v*) Projecting lantern and cine-projector

(*vi*) Human eye etc.

6.27. HUMAN EYE

A horizontal section of the eye is shown in Fig. 6.30. The eye is nearly spherical in shape. Its essential parts are given below :

(1) **Sclerotic** The outermost coating *S* of the eye is called the **sclerotic**. It is opaque, white and tough and forms the *white* of the eye. It protects and holds the eye-ball. The front portion *D*, of the opaque sclerotic is transparent and more convex than the remaining portion. This transparent portion which bulges out is called the **cornea**. Its refractive index is 1·337.

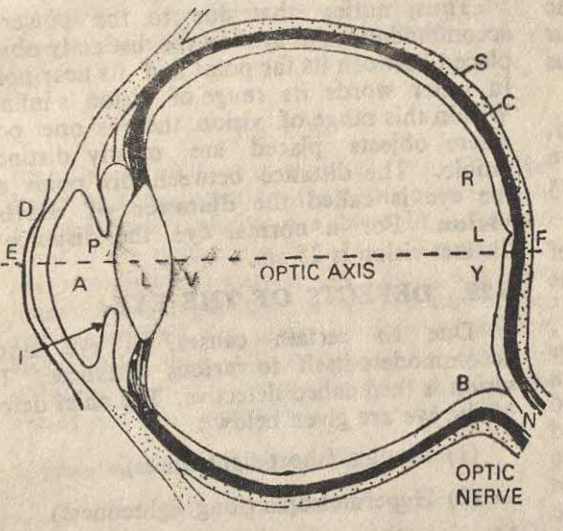


Fig. 6.30.

(2) **Choroid.** The second coat, *C*, inside the sclerotic is called **choroid**. It is a black membrane which forms the black of the eye and darkens the interior of the eye.

(3) **Retina**. The third coat, *R* which forms the innermost coating of the eye is called the **retina**. It is a semi-transparent, delicate membrane profusely supplied with nerve fibres and blood vessels. It is sensitive to light and serves the purpose of a sensitive screen for the reception of the images formed by the optical system of the eye.

The retina possesses the following two important points :

(*i*) **The yellow spot, y,** is situated at the centre of the retina. It is a slightly raised spot with a minute depression *L* at its summit. It is yellow in colour and most sensitive to light. The central region of the yellow spot is called the **fovea centralis**.

(*ii*) **The blind spot**, *B* where the optic nerve *N* enters the eye is also a raised spot but absolutely insensitive to light. It is not covered by the choroid and the retina.

(4) **Iris.** Behind the cornea there is an opaque diaphragm *I*, called the **Iris.** Its colour is different in different persons and also in persons of different countries.

The iris has a central circular aperture *P* called the **pupil.** The diameter of the pupil is regulated by the iris which can contract or relax by means of two sets of involuntary muscular fibres. In strong light, the aperture becomes small whereas in dim light it becomes large.

(5) **Lens.** Immediately behind the iris, there is a double convex crystalline lens *L*. Its back surface is more convex than its front surface. It is built of transparent concentric layers. The optical density of these layers increases *towards* the centre of the lens. The mean refractive index of the lens is 1·437. The lens is held in position by means of non-contractile tissues **suspensary ligaments** and connected to the sclerotic by the **ciliary muscles**. The ciliary muscles by contracting or relaxing change the curvature of the surfaces of the eye lens and hence change its focal length which is given by the formula.

$$\frac{1}{f}=(n-1)\left(\frac{1}{R_1}+\frac{1}{R_2}\right)$$

where f=focal length of the lens

n=Mean refractive index of the material of the lens.

R_1, R_2=Radii of curvature of the two surfaces of the lens.

(6) **Optic Axis**. The line, PY, passing through the centre of the cornea and that of the lens is called the **optic axis** of the eye.

(7) **Anterior Chamber** and **aqueous humour**. The space A between the lens L and the cornea D is called the **anterior chamber**. It is filled with a watery liquid containing a little common salt. This liquid is called the **aqueous humour.** Its refractive index is 1·337.

(8) **Posterior chamber** and **vitreous humour**. The space V between the retina R and the lens L is called the **posterior chamber**. It is filled with a viscous transparent liquid of refractive index 1·437. This liquid is called the vitreous humour.

Action of the Eye. As the cornea and aqueous humour have the same refractive index (1·337), they may be regarded to form a single homogeneous medium. Thus, on entering the eye rays of light from an object suffer *first* refraction through the cornea and the aqueous humour.

On emergence from the aqueous humour, the rays of light suffer a *second* refraction through the eye lens of mean refractive index 1·437.

On emergence from the eye lens, the rays of light suffer the *third* refraction through the vitreous humour of refractive index is 1·437.

After the above *three* refractions, the rays of light fall on the yellow spot of the retina and give rise to a real, inverted and diminished image of the object. The sensation produced on the eye is communicated to the brain by the optic nerve. *The brain interprets this inverted image as if it were erect.* In what manner the inverted image is interpreted as erect by the brain is not clearly understood.

6.28. POWER OF ACCOMMODATION

It has been stated in Art. 6.27 (5), that the focal length of the eye lens can be changed by contracting or relaxing the ciliary muscles. When these muscles contract, they thicken the lens or make its surfaces more convex thereby decreasing its focal length. This enables an observer to focus accurately the near object.

This power of the eye to change the focal length of the eye to suit the distance of an object is called its **power of accommodation**. The power of accommodation is greatest in the case of a child and decreases with advancing age.

Common experience tells us that the eye when fully relaxed can see simultaneously distant objects situated at different distances. A normal eye of a care free observer, when at rest, can see objects distinctly up to an infinite distance. The limit up to which an eye can see distinctly is called its **far point**.

On the other hand, it has been noticed that when an object is placed very close to the eye, it cannot be seen distinctly. The nearest point, where an object placed is distinctly visible, is called the **near point** of the eye. When an object is placed between the eye and its near point, it is not distinctly visible. For a normal eye, the near point is at a distance of about 15 cm.

The distance between the near point and the far point is called the **range of vision.**

Thus, notice that due to the power of accommodation an eye can see distinctly objects placed between its far point and its near point. In other words its range of vision is infinite. Within this range of vision, there is one point where objects placed are mostly distinctly visible. The distance between this point and the eye is called the **distance of distinct vision**. For a normal eye the distance of distinct vision is 25 cm.

6·29. DEFECTS OF THE EYE

Due to certain causes, an eye cannot accommodate itself to various distances. The vision is then called defective. The chief defects of the eye are given below :

(1) Myopia (short-sightedness),

(2) Hypermetropia (long-sightedness).

Myopia (Short sightedness)

A man suffering from **myopia** can see near objects but cannot see distinctly far off distant objects as his eye ball is *too long* for his lens or the eye lens become *too convergent*.

Due to the above defects, the image of an object situated beyond a certain distance, called **his far point**, is formed *in front of retina* and consequently is either not visible at all or indistinctly visible.

The myopia may be corrected by using a **concave lens** (divergent lens) of a suitable focal length so that parallel rays coming from distant objects after refraction through it appear to diverge from his far point.

Suppose the far point of a myopic eye is *P*. Rays starting from an object placed at *P* are focused by the eye lens on the retina and give rise to a distinct vision. Rays starting from an object placed *within P* and his near point *N'* are made to fall on the retina with the help of power of accommodation. It may be noted here that *his near point N'* is closer to the eye than the *normal near point N*. On the other hand, the rays starting from an object placed *beyond P* upto infinity are brought to focus *in front of* the retina Fig 6.31 (*i*). Consequently it is not distinctly visible. On placing a concave lens of focal length equal to the distance between the eye and his far point in front of the eye, the parallel rays will appear to diverge from *P* [Fig. 6.31 (*ii*)]. They will be focussed on the retina and thus give rise to a distinct vision.

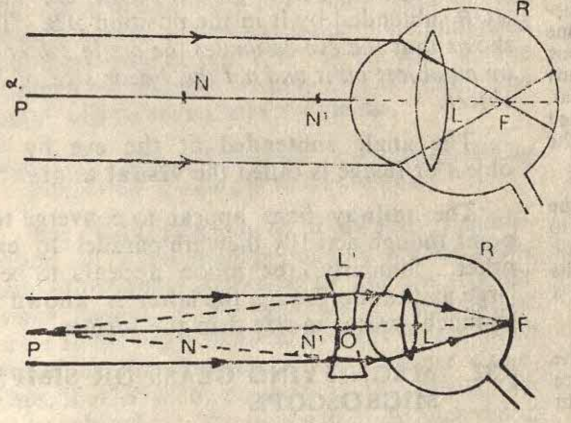


Fig. 6.31.

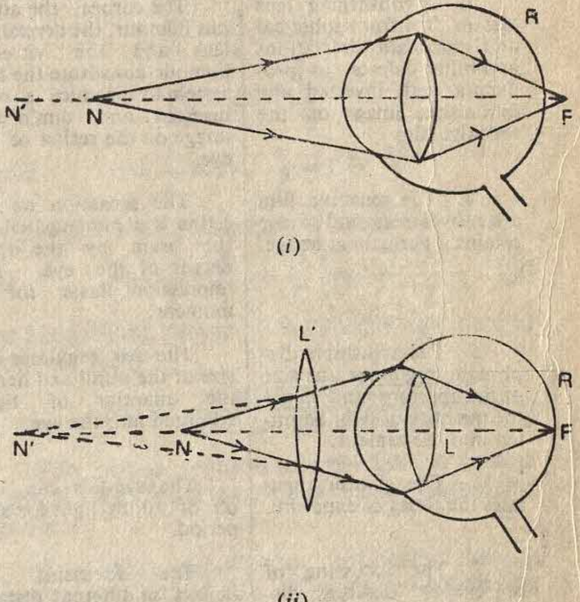
Hypermetropic (Long sightedness)

A man suffering from hypermetropia or long-sightedness can see distinctly distant objects but cannot see distinctly near objects lying within a certain point as his eyeball has become *too small* or his eye lens has become *less convergent*.

Due to the above defect, the image of a near object situated within a certain distance called **his distance of distinct vision**, is formed behind the retina and consequently is either not visible at all or indistinctly visible.

The hypermetropia may be corrected by using a **convex lens** (convergent lens) of a suitable focal length so that rays coming from an object placed at *the distance of normal distinct vision* (25 cm) after refraction through it appear to diverge from a point the *distance of distinct vision.*

Suppose a hypermetropic eye can see beyond *N'* upto infinity but objects lying between *N'* and *N* are not distinctly seen [Fig. 6.32 (*i*)] where *N* is the point at a distance of the normal distinct vision from the eye. Evidently *N'* is farther from the eye than *N*. The rays starting from an object placed at *N'* are focussed by the eye lens on the retina and give rise to a distinct vision. Rays starting from an object lying beyond *N'* upto infinity are focussed on the retina by the eye lens by means of the power of accommodation. But the rays starting from an object placed between *N'* and *N* or at *N* are brought to focus *behind* the retina Consequently, it is not distinctly visible. On placing a convex lens of such a focal length that a virtual image of an object placed at *N* is formed at *N'* [Fig. 6.32(*ii*)] so that rays appearing to come from *N'* are focussed on the retina.



(*i*)

(*ii*)

Fig. 6.32

6.30 COMPARISON BETWEEN A PHOTOGRAPHIC CAMERA AND THE EYE

Camera	Eye
1. The light-tight box to prevent the extraneous light from outside.	The opaque sclerotic to prevent the extraneous light.
2. The box is darkened from inside to stop reflection within the camera.	The sclerotic is lined with dark charoid, to stop reflection within the eye.
3. A converging lens system free from spherical and chromatic aberrations and other defects to produce a real, inverted and diminished image on the sensitive film.	The cornea, the aqueous humour, the crystalline lens and the vitreous humour constitute the lens system to produce a real, inverted and diminished image on the retina of the eye.
4. The sensitive film after *developing* and *fixing* retains a permanent image.	The sensation on the retina is communicated to the brain by the optic nerves of the eye. The impression lasts for a moment.
5. The adjustable diaphragm regulates the size of the aperture and hence the quantity of light admitted into the camera.	The iris regulates the size of the pupil and hence the quantity of light admitted into the eye.
6. The shutter regulates the times of exposure.	The eye-lids can cut off or admit light for any period.
7. The focussing of objects at different distances is done by changing the distance between the lens and the screen which is subsequently replaced by a sensitive film.	The focussing of objects at different distances is done by the power of accommodation of the eye.

6.31. ANGULAR VISION

Consider an object *AB* placed in front of the eye at a certain distance (Fig. 6.33). The image formed on the retina is *ab*. If the same object is brought nearer to the eye and placed in the position *A′B′*, the image formed is *a′b′*. Clearly, *a′b′* is greater than *ab*. Thus, to the eye the object in the position *AB* appears smaller than when it is placed in the position *A′B′*. It shows that the apparent size of an object depends upon its distance from the eye.

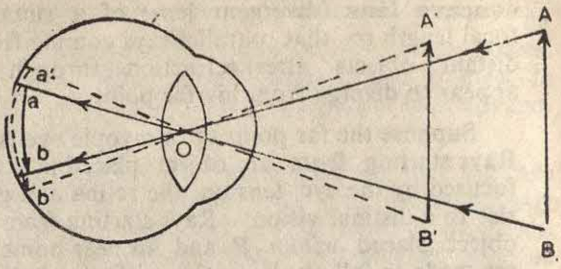


Fig. 6.33

From the figure 6.33, it is clear that the angle *A′OB′* subtended at the eye by the object in the position *A′B′* is *greater* than the angle *AOB* subtended by it in the position *AB*. This shows that *the eye estimates the angle subtended by an object on it and not the linear size of the object*.

The angle subtended at the eye by the object or image is called the **visual angle.**

The railway lines appear to converge to a point though actually they are parallel to each other. Similarly, the moon appears to be as large as the sun though the latter is known to be much greater in size than the former.

6.32. MAGNIFYING GLASS OR SIMPLE MICROSCOPE

To see the fine details of a small object, we have to bring it as near the eye as possible so that the angle subtended by it at the eye may increase and so appear to be large. But there

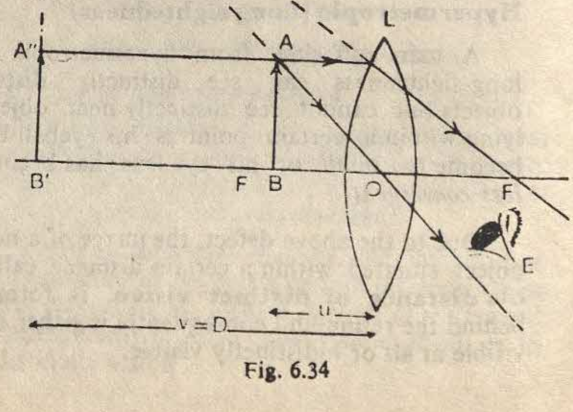


Fig. 6.34

is a limit upto which it can be brought closer to the eye. If it is placed within the distance of distinct vision, it is not distinctly visible. Consequently to study a minute object we make use of magnifying glass or simple microscope which produces a virtual image at the distance of distinct vision of an object placed close to the eye.

A magnifying glass or a simple microscope is an ordinary convex lens of short focal length. When an object *AB* is placed within the principal focus of the convex lens *L* (Fig. 6.34), the eye *E* placed on its other side sees the virtual image *A'B'*. The distance of the object between *F*, the focus, and *O*, the optical centre of the lens *L* may be so adjusted that the virtual image *A'B'* is formed at the distance of distinct vision, *D* (25 cm). The image will be then distinctly visible.

Angular Magnification or Magnifying Power of a simple Microscope

The magnifying power or angular magnification of a microscope may be defined *as the ratio of the angle subtended at the eye by the image formed at the distance of the distinct vision to the angle subtended by the object when placed at the distance of the distinct vision.* Thus, if *A"B'* is the position of the object *AB* when placed at the distance of distinct vision and the eye *E* is very close to the lens L, we have

Magnifying power of the simple microscope or magnifying glass

$$=\frac{\text{Angle subtended at the eye by the } \textit{image formed} \text{ at the distance of the distinct vision}}{\text{Angle subtended at the eye by the } \textit{object placed} \text{ at the distance of the object vision}}$$

$$=\frac{\angle A'OB'}{\angle A''OB'}\left[\begin{array}{l}\text{For the sake of clarity}\\ A''O \text{ has not been joined}\end{array}\right]$$

$$=\frac{\angle AOB}{\angle A''OB'}$$

$$=\frac{\tan\angle AOB}{\tan\angle A''OB'}\left[\begin{array}{l}\text{When } \theta \text{ is small and}\\ \text{in radians, } \theta=\tan\theta\end{array}\right]$$

$$=\frac{AB/OB}{A''B'/OB'}$$

$$=\frac{AB}{OB}\,\frac{OB'}{A''B'}$$

$$=\frac{OB'}{OB}\quad [\because\ AB=A''B']$$

or $$m=\frac{D}{u} \qquad \ldots(1)$$

where $D=OB'=$Distance of the distinct vision from the lens or eye and

$u=OB=$Distance of the object from the lens or eye

$m=$Magnifying power of the convex lens or simple microscope.

Since the image *A"B'* formed at the distance *D* is virtual, therefore $v=-D$. According to the lens formula

$$\frac{1}{v}-\frac{1}{u}=\frac{1}{f}$$

$$\therefore\quad \frac{1}{u}=\frac{1}{v}-\frac{1}{f}$$

and $$m=\frac{v}{u}=1-\frac{v}{f}=1+\frac{D}{f}$$

where *f* is the focal length of the convex lens

or $$m=\frac{D}{u}=\left(1+\frac{D}{f}\right)=1+\frac{25}{f} \qquad \ldots(2)$$

or Magnifying power of the simple microscope (convex lens)

$$=1+\frac{\text{Distance of distinct vision}}{\text{Focal length of the convex lens}}$$

The above relation shows that a convex lens of short focal length has large magnifying power.

A simple microscope ordinarily has a magnifying power 20. If greater magnifying power is required, we use a compound microscope.

6.33. COMPOUND MICROSCOPE

A compound microscope is an optical instrument which is used to magnify very small objects like blood cells, bacteria etc., which otherwise cannot be seen clearly with the naked eye.

The essential parts of a compound microscope are two *convex lenses of short focal length.

(1) **The object glass or objective,**

(2) **The eye-piece or lens.**

The distance between the object and the objective is little greater than the focal length

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*The lenses used in practice are combination of lenses in order to minimise spherical and chromatic aberrations.

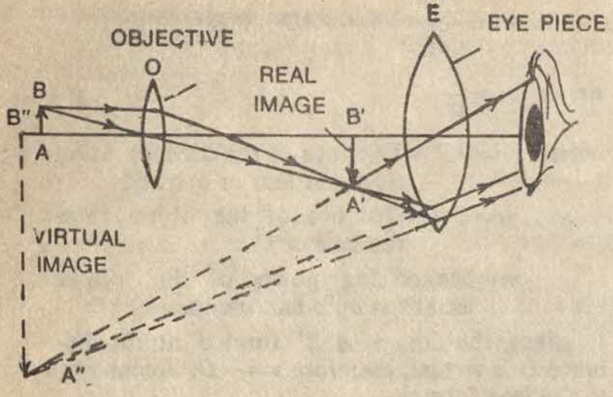


Fig. 6.35

of the objective. Consequently a real, inverted, magnified image is produced on the other side of the lens. In Fig. 6.35, AB is the object, $A'B'$ is the real, magnified, inverted image formed by the objective O. This real image is then viewed through the eye lens which acts in exactly the same way as a magnifying glass (See Art. 6.32).

The distance between the real image and the eye-lens is less than the focal length of the lens consequently a magnified virtual image is produced. The lens is adjusted so that this virtual image is formed *at the least distance of distinct vision* usually taken as 25 cm from the eye. $A'B'$ is the real image formed by the objective, $A''B''$ is the virtual image formed by the eye-piece E.

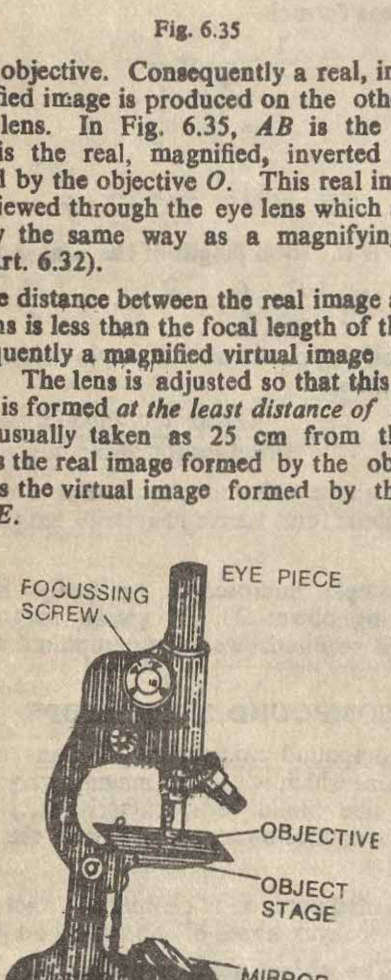


Fig. 6.36. Compound microscope.

The magnifying power of the compound microscope is defined as the ratio of the angle subtended at the eye by the image to the angle subtended at the eye by the object when placed at the least distance of distinct vision.

Thus for a compound microscope, the magnifying powers of magnification is

$$m=\frac{A''B''}{AB}$$

or

$$m=\frac{A''B''}{A'B'}\cdot\frac{A'B'}{AB}$$

$$=m_e\times m_o$$

where m_e is the magnification produced by eye piece and m_o is the magnification produced by the objective.

The magnification produced by a good compound microscope is upto 2000 or more. The object must be strongly illuminated if a bright image is to be seen.

6.34. ASTRONOMICAL TELESCOPE

It is an optical instrument used to see heavenly bodies.

The astronomical telescope consists of two convex lenses ;

(*i*) the objective O of very **long** focal length and wide aperture, and

(*ii*) the eye-piece E of very **short** focal length and small aperture.

The eye-piece E is fixed in a brass tube which can slide in the second tube at the other end of which the objective O is fixed. The objective and the eye-piece are not single lenses but convergent combination of lenses free from spherical and chromatic aberrations and other defects.

Let XY be the common principal axis of the objective O and the eye-piece E. Imagine that the objective O is facing a distant object. Let it be situated at right angles of XY produced. Since the object is far off we may suppose that a parallel beam started from its top. This parallel beam is inclined to the XY at a small angle α (Fig. 6.37).

If the beam had been parallel to XY, after refraction through the objective O, it would have been brought to its principal focus F lying on its principal axis XY. Since it is inclined to XY, it is brought to focus at I which lies on the *secondary axis* or the focal plane. Thus, I is the image of the top of the object. Draw IF

perpendicular to *XY*. Then *IF* is the image of the distant object formed by the objective *O*. The image *IF* is real, inverted and diminished.

Suppose *IF* is at the principal focus of the eye-piece *E*. A ray *IE* passing through its optical centre will go straight along *IEC*. Other rays from the image *I* after refraction through the eye-piece *E* will be formed at infinity. This adjustment of the telescope is called **normal adjustment** This is shown in Fig. 6.37.

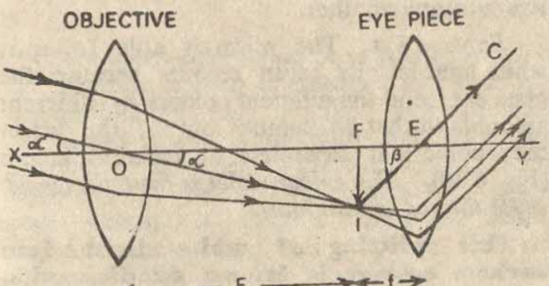


Fig. 6.37

If the image *IF*, lies between the focus F_e and the optical centre of the eye-piece *E*, the final image *A'B'* will be virtual and magnified but inverted in the original sense of the object. The distance of the eye-piece *E* from *IF* can be so adjusted that the image *A'B'* is formed at distance of distinct vision. This is shown in (Fig. 6.38).

In order to trace the course of rays forming the final image *A'B'* we need to take two rays. The ray *IL* travelling parallel to the principal axis *XY*, after refraction at the eye-piece *E* passes through its principal focus F_e. Another ray *IE* passing through its optical centre goes straight along *IEC*. These rays when produced backwards appear to meet at *A'* which is, therefore, the virtual image of *I* The other rays forming the image *I* after refraction at the eye-piece also appear to diverge from *A'*. Draw *A'B'* perpendicular to *XY*. Then *A'B'* is the final image. It is *virtual* erect in the sense of *IF* but *inverted* in the sense of the distant object, and magnified.

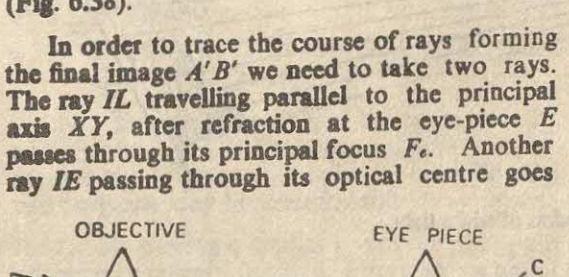


Fig. 6.38

Since the final image formed by it is inverted, the telescope described above is used for seeing the *celestial objects* only.

Magnifying power of the Astronomical Telescope may be defined as the ratio of the angle subtended at the eye by the image to the angle subtended at the eye by the object.

It can be proved mathematically that

$$m=\frac{F}{f}$$

where m = magnifying power or angular magnification of the telescope.

F = focal length of the objective

and f = focal length of the eye-piece.

For high angular magnification or **magnifying** power, it is clear from the above expression that *F*, the focal length of the objective should be large whereas the focal length of the eyepiece should be small.

It will be noted that distance between the objective *O* and the eye-piece *E* is equal $F+f$ when the telescope is in *normal adjustment* (Fig. 6.37).

When the telescope is adjusted in such a way that the final image is formed at the distance of the distinct vision (Fig. 6.38), the length of the telescope is *slightly* less than $F+f$.

The objective of the Yerkes telescope has a diameter of 1·08 m and a focal length of 18·6 cm. Its eye-piece is of focal length 0·64 metre. Its weight is about 23 quintals. Its magnifying power is about 300.

6.35. DISPERSION OF LIGHT BY A PRISM (The splitting of white light)

Take a prism or a lens ; hold it close to your eye and use it to view objects in the room You will find that the edges of the various objects appear to be of several colours. This will be seen most easily through a glass prism.

Sir Isaac Newton was the first to investigate the effect. Sometime in 1666 Newton darkened his room at Trinity College, Cambridge, and allowed a beam of sunlight to pass through a small, circular hole in the shutter of his room, forming a white, circular patch on the opposite wall. He then placed a triangular glass prism in the path of the beam of light. He found, firstly, that the white spot on the wall had changed its position and, secondly, the light was no longer white but coloured.

Newton examined the colours very carefully and could make out the seven colours of the rainbow : *red, orange, yellow, green, blue, indigo* and *violet*, in that order. But there was no clear distinct line between one colour and the other. **This coloured band he called a spectrum.**

Now try to produce a spectrum yourself.

Experiment. *To produce a spectrum of white light*.

Requirements. The ray apparatus producing white light, triangular glass prism, white screen.

Procedure. Let a narrow beam of white light from the ray apparatus strike the prism and allow the beam that comes out of the prism to strike the white screen. Examine what appears on the screen (Fig. 6.39).

On the screen, instead of white light which you would see at *A* in the absence of the prism, you should now see coloured light at *B*. If you look carefully you will be able to make out the seven colours of the rainbow in the order given above. You will not be able to see each colour standing separately, as they all run into one another.

Explanation. The prism is able to split white light into its seven colours because the glass can bend the different colours by different amounts so that on coming out of the prism they come out separately at different angles (Fig. 6.39). *The colour violet is bent the most, while the red is bent least*.

This splitting of white light into various colours is known as dispersion and the colours obtained on the screen form the spectrum of white light.

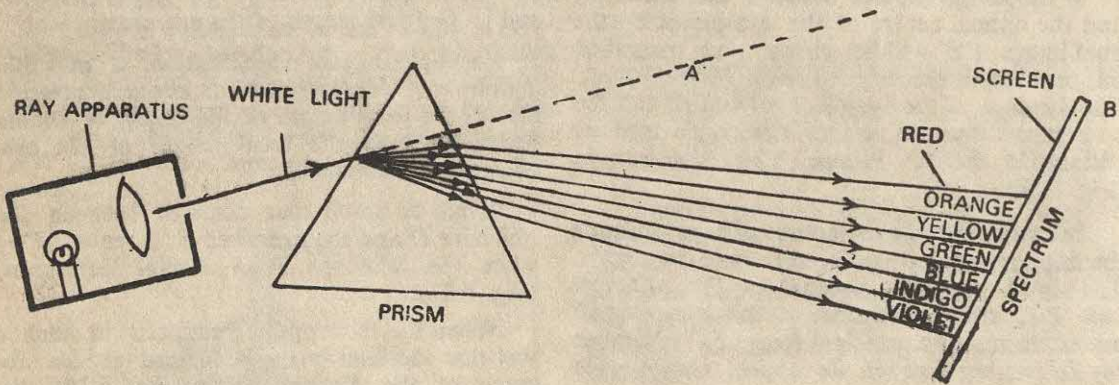


Fig. 6.39. Dispersion of white light.

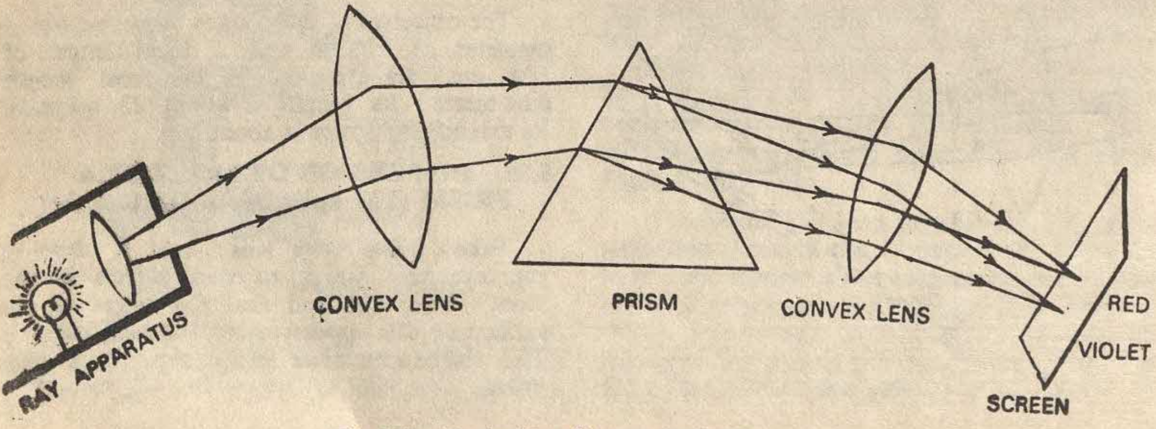


Fig. 6.40. Production of a pure spectrum.

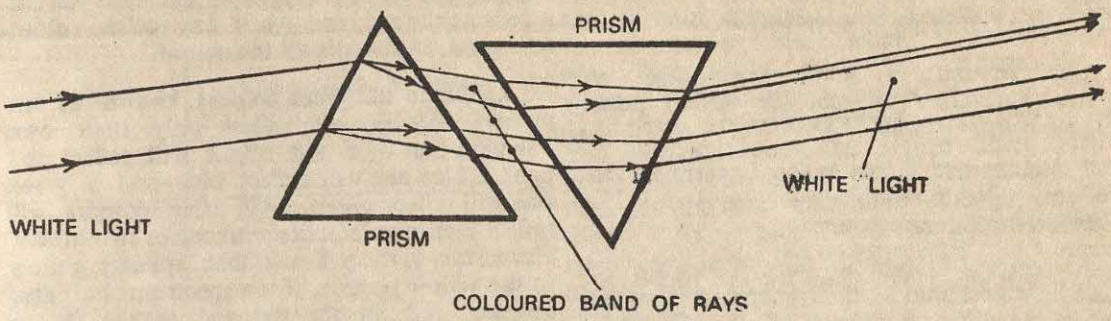


Fig. 6.41. Re-combining colours to give white light.

Pure spectrum. It has been said above that the spectrum consists of colours which run into one another, *i.e.*, they overlap. The spectrum as formed above is therefore not pure. By combining the prism with two lenses, it is possible to produce a pure spectrum in which each colour is distinct from the other. Fig. 6.40 shows how this is done. The slit through which the light originates must be narrow, and the prism must be placed in a **special** position. You will learn more about this in the higher classes.

Newton wanted to know if each colour could be split further, and so he made a tiny hole in the screen to let out each colour of the spectrum on to another prism. But he discovered that there was no further split, and therefore concluded that the seven colours were pure colours.

6.36. COMBINATION OF COLOURS TO GET WHITE LIGHT

Just as white light can be split into its component colours, so these colours can be recombined to give white light. The following two methods may be used for this :

1. By placing a similar prism in the path of the split colours but in a direction opposite to the first prism, as in (Fig. 6.41). Note that the two prisms combined behave as the ordinary glass block and the emergent white beam is parallel to the incident white beam.

2. By using Newton's Disc. Newton's disc is a circular piece of cardboard on which are painted the seven colours of the spectrum in their correct proportion. When the disc is rotated rapidly the colours will merge together to give a white colour if pure spectral colours are used (see Fig. 6.42). This is because our eyes possess a property known as *persistence* or *duration of vision* ; the light from one colour forms an image which persists on the retina until each of the other colours in turn has been reflected to the eye. Thus, in effect, we see all of them at once, and they blend together to give a white effect. Because certain colours fade rapidly, it may not be possible to get a pure white effect.

6.37. RAINBOWS

These are formed in the same way as the spectrum is formed by a glass prism. They are formed not by glass but by tiny drops of water suspended in the sky soon after rainfall. The white beam of light comes from the sun and passes through these spherical transparent water drops. On coming out of the drops, the white beam is split into the seven colours of the rainbow.

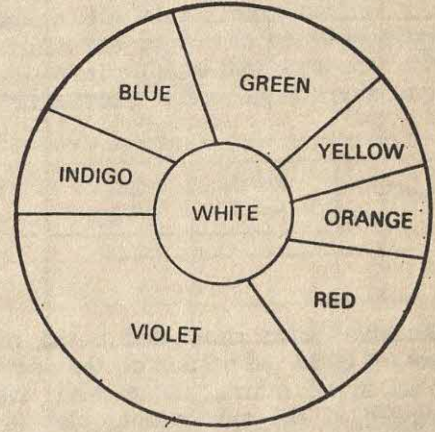


Fig. 6.42. Newton's disc.

6.38. COLOUR OF OPAQUE OBJECTS

Try the following experiment.

Experiment. *To study the colour of objects as seen by light from the various parts of the spectrum of white light.*

Requirements. Same as for Experiment to produce spectrum of white light in Art. 6.35 : ribbons of different colours.

Procedure. Obtain a pure spectrum of white light and hold all the ribbons in turn in each of the different colours of the spectrum. Note the colour of the ribbon as seen in each colour of the spectrum.

Record your observation in the following manner.

Colour in Spectrum	*Colour of ribbon in daylight*			
	Red	*Yellow*	*Green*	*Blue*
Red				
Orange				
Yellow				
Green				
Blue				
Indigo				
Violet				

The table should show that a red ribbon appears red in the red portion of the spectrum and black in all others, and a white ribbon appears red in the red portion, blue in the blue portion, yellow in the yellow portion and so on.

Explanation. Every object is seen by the light it reflects to the eyes. The fact that a ribbon appears red in white and in red light but black in all other colours shows that the ribbon can only reflect red light while it absorbs all other colours. When white light falls on it, it reflects the red portion and absorbs all others ; when red light falls on it, it reflects the red, and when any other colour falls on it, it absorbs all the colour.

Red, blue and green colours, known as the *primary colours,* will reflect only their own colours ; that is, a red object will reflect red light, a blue one will reflect blue and a green one will reflect green. All other colours will reflect their own colours with one or two others. For instance, the yellow ribbon appears yellow in the yellow portion of the spectrum but also appears red in the red and orange in the orange portion. This means that the yellow ribbon, apart from reflecting yellow light, is also able to reflect red and orange.

The experiment explains the colour of opaque objects. *The colour of an opaque object depends on the colour that is reflected by it. This in turn depends on the colour of the light incident on it.* The yellow costume put on by an actor on the stage suddenly turns green when green light shines on it and red when red light falls on it, while a red costume suddenly turns black when green light shines on it. The colour generally ascribed to an object is the colour it presents when white light falls on it, that is, in daylight. For example, we say a book cover is red because it appears red in daylight.

You will have had the sad experience of buying a dress or a shirt which appears very beautiful in artificial daylight from the lamps inside the shop and turns out to be some other colour on coming out of the shop.

Coal appears black in all colours, because it cannot reflect any colour ; it absorbs all of them.

6.39. COLOUR OF TRANSPARENT OBJECTS

Try the following experiment :

Experiment. *To study the colour of transparent objects as seen by light from the various parts of the spectrum of white light.*

Requirements. Same as for Experiment to produce spectrum of white light in Art. 6.35 ; coloured filters (glass or plastic).

Procedure (*a*) Obtain a pure spectrum of white light on a white screen. Hold each filter between the prism and the screen. Note the colours that remain on the screen.

Record your observation in the following manner :

Colour of filter	*Colours seen on the screen*
Red	
Blue	
Orange	
Green	
etc.	

You will notice that each of the filters allows its own colour to pass through. In particular, the red, green and blue (the primary colours) allow *only* their own respective colours to pass, while each of the others allows one, two or even three other colours to pass along with their own colour. For instance, the orange filter will allow red, orange, yellow and green to pass through it.

(*b*) Hold each coloured filter close to your eye and use it to view the different coloured objects you can find around you : *e.g.*, clothes, books and walls.

Record your observation in the following table :

Colour of filter	*Red book*	*Blue dress*	*Yellow dress*	*Green bottle*	*Pink wall*	*Brown table*	*Coal*
Red							
Green							
Yellow							
Blue							
etc.							

You will notice from the above table that the red book appears red when viewed through the red filter, but black when viewed through any other filters. Also the yellow dress appears yellow through the yellow filter, but, in addition, appears red through the red filter and orange through the orange filter. The green bottle also appears green through a green filter and the blue dress blue through a blue filter. Only the red, the green and the blue books will give this result while all other colours will give results similar to those of the yellow one.

Explanation. The colour of transparent objects depends on the colour of light which they allow to pass through them (*i.e.*, which they transmit). A green glass is green because it allows green light to pass through it and absorbs all other colours. If placed in yellow light it will appear black, as it does not allow yellow light to pass through it, *i.e.*, it absorbs it.

Red, green and blue filters transmit *only* their own colours and absorb all others, whereas other coloured filters transmit their own colours and one or two other colours.

6.40. LIGHT AS A WAVE

There are many phenomena that occur with light and are due to its wave nature. Light waves exhibit the properties of other waves ; but there are other things that occur with waves *i.e.*, interference ; diffraction ; polarization because they are particularly impressive with light.

When the opportunity arises, take a good look at soap bubbles or soap films or oil films on water. Note the colours of the reflected light, sometimes brilliant, continually changing colours. These result from the wave nature of light (Interference of light). The wave properties of light are more diverse and more important than the colours in soap bubbles, yet that is a simple, familiar phenomenon that demonstrates the existence of light waves.

The waves of light are very short and they cover a broad range. The wavelength is associated with colour. The longest waves, those at the red end of the spectrum, are about 0·00007 cm in length in air (0·7 *μm* or 700 *nm*) while at the violet end the wavelength is 0·00004 cm (0·4 *μm* or 400 *nm*). Because of this small wavelength, is it any wonder that the establishment of the wave nature of light was a long and difficult process ?

If you look at a distant lighted electric bulb through your two fingers just touching each other with a little gap in between, you will see a small pattern of fringes. This is formed due to diffraction of light.

Light is not a material vibration like sound, but it is an oscillating electric and magnetic field. Because of this, light can pass through a vacuum whereas sound, which is a material wave, cannot. The speed of light is $3\cdot00\times10^8$ ms^{-1} or 3×10^5 km/s in a vacuum, almost exactly the same in air, but somewhat less in a denser medium.

Like radio waves, light is an electromagnetic wave. Basically radio waves, television signals ; microwaves ; heat waves ; light ; ultra violet light and *X*-rays, all belong to the same category. These waves differ only in their frequencies ; within visible region, the colours, red, orange, yellow, green, blue, indigo, violet have respectively higher frequencies.

SOLVED EXAMPLES

Example 1.

A ray of light is incident on a slab of glass at an angle of 45°. If the refractive index of glass is 1·6", what is the angle of refraction ? What is the critical angle of glass ?

Solution.

Here, Angle of incidence $=i=45°$

Refractive index of glass with respect to air $={}^a n_g=1\cdot60$

Angle of refration$=r=?$

Critical angle of glass$=i_c=?$

Since $\dfrac{\sin i}{\sin r}={}^a n_g$ (Snell's Law)

$$\therefore \quad \frac{\sin 45°}{\sin r}=1\cdot60$$

$$\text{or} \quad \frac{0\cdot7071}{\sin r}=1.60$$

$$\therefore \quad \sin r=\frac{0\cdot7071}{1\cdot6}=0\cdot441$$

$$\text{Hence} \quad \boxed{r=26°\ 10'}$$

$(\because \sin 26°\ 10'=0\cdot441)$

Again $\sin i_c=\dfrac{1}{{}^a n_g}$ where i_c=Critical angle of glass

$$\therefore \quad \sin i_c=\frac{1}{1\cdot60}=0\cdot625$$

$$\therefore \quad i_c=38°\ 40' \qquad (\because \sin 38°40'=0\cdot625)$$

Example 2.

A glass slab is 6 cm × 3 cm × 12 cm in size. It can be placed on a line drawn on a white paper with any of the three dimensions vertical. How much does the line appear to be raised up in each case when seen through glass ? Refractive index of glass is 1·50.

Solution.

We known that

$${}^a n_g=\frac{\text{Real depth}}{\text{Apparent depth}}$$

$$\therefore \quad \text{Apparent depth}=\frac{\text{Real depth}}{{}^a n_g}$$

Here, ${}^a n_g=1\cdot50$

(*i*) When the real depth=6 cm

$$\text{Apparent depth}=\frac{6}{1\cdot5}=\mathbf{4\ cm}$$

Thus the line appear to be raised up by 2 cm.

(*ii*) When the real depth=3 cm

$$\text{Apparent depth}=\frac{3}{1\cdot5}=2\text{ cm}$$

Thus the line appear to be raised up by 1 cm.

(*iii*) When the real depth=12 cm

$$\text{Apparent depth}=\frac{12}{1\cdot5}=8\text{ cm}$$

Thus the line appear to be raised up by 4 cm.

Example 3.

Consider a right-angled prism *ABC* (Fig. 6.43). What should be the minimum refractive index of glass so that light incident normally on the face *AC* is totally internally reflected by face *BC*. It will then come out normally from face *AB*.

Solution.

Since the ray of light *PN* is incident normally (*i.e.*, $i=0$) on the face *AC* so its angle of refraction is *zero*. In other words, the ray *PNO* will pass through the glass prism *undeviated*. This ray falls on the face *BC* at *O* and is totally internally reflected at *O* and then comes out normally from face *AB*.

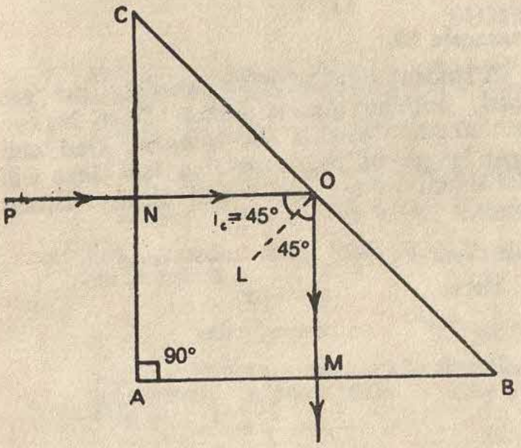


Fig. 6.43.

By geometry, $\angle NOM=90°$

Let *OL* be the normal at *O*.

$\therefore$ $\angle NOL$=angle of incidence

and $\angle MOL$=angle of reflection

Since $\angle NOL=\angle MOL$ (Laws of reflection)

$\therefore$ $\angle NOL=45°$

If the ray *PNO* is to be totally internally reflected at *O*, it must fall at *O* at an angle *equal* to the critical angle (i_c) for glass for the refractive index of glass to be minimum.

$\therefore$ Critical angle of glass$=i_c=45°$

$$\text{Now}\quad {}^an_g=\frac{1}{\sin i_c}$$

$\therefore$ Minimum refractive index of glass

$$={}^an_g=\frac{1}{\sin 45°}=\frac{1}{0\cdot7071}=1\cdot414$$

Example 4.

A thin lens has a focal length of −25 cm. What is the power of the lens and what is its nature ?

Solution.

Power of a lens (in dioptres)

$$=p=\frac{1}{\text{focal length in metre}}$$

$$=\frac{100}{\text{focal length in cm}}$$

$$=\frac{100}{-25}=-4\text{ dioptres}$$

It is a concave (or diverging) lens.

Example 5.

A convex lens of focal length 5 cm is used as a simple microscope. What is its magnifying power if the final image is at the distance of distinct vision (25 cm) ? If it is used as eyepiece in a compound microscope with objective of magnifying power 40, what is the magnifying power of the compound microscope ?

Solution.

Magnifying power of a simple microscope

$$=1+\frac{D}{f}$$

$$=1+\frac{25}{5}$$

$$=1+5=6$$

Since, magnifying power of a compound microscope

=magnifying power of the objective × magnifying power of the eyepiece

or $m=m_o\times m_e$

$=40\times6$

$=240$

Example 6.

A ray of light is incident on a glass slab at an angle of incidence i. Let the angle of refraction be r. If $i+r=90°$, show that $\tan i={}^{a}n_{g}$.

Solution.

Let ${}^{a}n_{g}$ = Refractive index of glass slab

Angle of incidence $= i$

Angle of refraction $= r$

According to Snell's Law of refraction

$$\frac{\sin i}{\sin r}={}^{a}n_{g} \qquad ...(1)$$

Now, $i+r=90°$ (given)

$$\therefore \quad r=90-i$$

or $\sin r=\sin(90-i)=\cos i$ ...(2)

Putting (2) in (1), we have

$$\frac{\sin i}{\cos i}={}^{a}n_{g}$$

or

$$\boxed{\tan i={}^{a}n_{g}}$$

Example 7.

A man whose least distance of distinct vision is 25 cm uses a convex lens of 3 cm focal length as a magnifying glass. Find the magnification he obtains.

Solution.

Here, $D=25$ cm and $f=3$ cm

$\therefore$ Magnifying power of the magnifying glass

$$=1+\frac{D}{f}$$

$$=1+\frac{25}{3}=\frac{28}{3}=9\tfrac{1}{3}$$

Example 8.

The focal lengths of the object glass and eye lens of an astronomical telescope are cm, and 5 cm, respectively. Find its magnifying power.

Solution.

Here, $F=60$ cm and $f=5$ cm

$\therefore$ Magnifying power $=\frac{F}{f}=\frac{60}{5}=\mathbf{12}$

Example 9.

It is required to project a 3 cm square slide so as to give 30 cm square picture on a screen at a distance of 11 metre from the slide. What should be the focal length of the projecting lens you would use and where would you place it ?

Solution.

Length of each side of the slide $=O=3$ cm

Length of each side of the picture

$$=I=30 \text{ cm}$$

$$u+v=11 \text{ m} \qquad ...(i)$$

$$\therefore \quad \frac{I}{O}=\frac{v}{-u}$$

$$\therefore \quad \frac{30}{3}=\frac{v}{-u}$$

or $v=-10u$ ...(ii)

Putting (ii) in (i), we get

$$-u-10u=11$$

$$u=-1 \text{ m} \qquad ...(iii)$$

Putting (iii) in (ii), we get,

$$v=10 \text{ m} \qquad ...(iv)$$

Now $\frac{1}{f}=\frac{1}{v}-\frac{1}{u}=\frac{1}{10}+\frac{1}{1}=\frac{11}{10}$

$$\therefore \quad f=\frac{10}{11} \text{ m}$$

Example 10.

A student with defective eye-sight can see clearly nothing that is further from his eye than 50 cm. What is the number, kind and focal length of the correcting lens that will enable him to see easily and clearly distant object ?

Solution.

Here, $u=-\infty$

$v=-50$ cm

Power of the lens $=p=?$

$$\therefore \quad \frac{1}{f}=\frac{1}{v}-\frac{1}{u}$$

$$\frac{1}{f}=\frac{1}{-50}+\frac{1}{\infty}$$

$$\therefore \quad f=-50 \text{ cm}$$

Hence, power of the lens $=p$

$$=\frac{100}{\text{focal length in cm}}=\frac{100}{-50}$$

$= \mathbf{-2}$ **dioptres**

Thus a *concave lens* of focal length 50 cm is required. Its power is -2 dioptres.

Example 11.

A long-sighted person whose nearest distance of distinct vision is 50 cm finds that this distance is reduced to 20 cm by using spectacles. Find the nature and focal length of the lens used.

Solution.

Here,
$$u = -20 \text{ cm}$$
$$v = -50 \text{ cm}$$
$$f = ?$$

$$\because \quad \frac{1}{f} = \frac{1}{v} - \frac{1}{u}$$

$$\therefore \quad \frac{1}{f} = \frac{1}{-50} - \frac{1}{-20}$$

$$= -\frac{1}{50} + \frac{1}{20}$$

or
$$\frac{1}{f} = \frac{3}{100}$$

or
$$f = \frac{100}{3} = \mathbf{33{\cdot}33 \text{ cm}}$$

Thus a *convex lens* of focal length 33·33 cm is required.

Example 12.

An object 60 cm from a lens gives a virtual image at a distance of 20 cm infront of the lens. What is the focal length of the lens? Is the lens converging or diverging? Give reason for your answer.

Solution.

Here,
$$u = -60 \text{ cm}$$
$$v = -20 \text{ cm}$$

$$\because \quad \frac{1}{f} = \frac{1}{v} - \frac{1}{u}$$

$$\therefore \quad \frac{1}{f} = \frac{1}{-20} - \frac{1}{(-60)}$$

$$= -\frac{1}{20} + \frac{1}{60}$$

$$= -\frac{1}{30}$$

$$\therefore \quad f = -30 \text{ cm}$$

Since the focal length of the lens is *negative* and it *diverges* the beam of light on refraction in order to give virtual image in front of the lens so the lens is *diverging* or *concave* and its focal length is 30 cm.

SUMMARY

1. *Refraction* (or optical refraction) is the bending of light rays as they pass obliquely from one medium into another of different optical density.
2. *Laws of refraction.* (*i*) The incident, refracted ray and the normal all lie in the same plane.

   (*ii*) For two given media, $\frac{\sin i}{\sin r}$ is a constant, where i is the angle of incidence and r is the angle of refraction. The constant is denoted by n.
3. *Refractive index.* When light travels from medium 1 into a medium 2, the refractive index ${}^1n_2$ can be defined as

$$ {}^1n_2 = \frac{\sin i}{\sin r} $$

4. *Relations between refractive indices.* We denote the refractive index from water to air by ${}^wn_a$ and similarly for other refractive index values. ${}^gn_a$ is the refractive index from glass to air. Note that

$$ {}^wn_a = \frac{1}{{}^an_w} $$

$$ {}^wn_g = {}^wn_a \times {}^an_g = \frac{{}^an_g}{{}^an_w} $$

5. *Light travelling from one medium to another* : "$n \sin i$" is a constant quantity where n is the absolute refractive index of that medium and i is the angle made by the ray in that medium with the normal. Thus from glass to water

$$ n_g \sin i_g = n_w \sin i_w $$

When light travels from air to water to glass, the boundaries of the media being parallel, "$n \sin i$" is again a constant quantity. Thus, if $n_a(=1)$ is the refractive index of air, then

$$n_a \sin i_a = n_w \sin i_w = n_g \sin i_g.$$

6. Refractive index $(n) = \dfrac{\text{Real depth}}{\text{Apparent depth}}$.

7. *Refraction through a parallel—sided plate.*

   (*i*) The emergent ray is parallel to the incident ray. In other words, the angle of incidence is equal to the angle of emergence.

   (*ii*) The emergent ray is displaced laterally with respect to the incident ray.

   (*iii*) The lateral displacement, for a given angle of incidence, is proportional to the thickness of the plate.

8. *Total internal reflection* : *Critical angle*. Two conditions are necessary for total internal reflection to occur :

   (*i*) The light must travel from a dense to a less dense medium.

   (*ii*) The angle of incidence in the dense medium must be greater than the critical angle, i_c, between the two media.

   The *critical angle*, i_c, is defined as the angle of incidence in the dense medium when the angle of refraction in the less dense medium is 90°.

9. *Mirage* is an optical illusion, in which inverted images of distant objects are seen, as if reflected from a pond or a lake or sometimes, as if suspended in the atmosphere. It can be explained on the basis of total internal reflection.

10. The *light pipe* is a curved rod of glass or transparent plastic so that light entering through one end undergoes total internal reflection at several points (provided the curvature of the rod is not too great) and emerges through other end.

    The whole study area based upon this principle is called *fiber optics*. It finds many uses in practical day life.

11. A *lens* is a piece of transparent material, usually glass, bounded by two spherical surfaces. Essentially, there are two types of lenses :

    (*i*) *Convex lenses* which are thicker at the centre than at the edges, and

    (*ii*) *Concave lenses* which are thinner at the centre than at the edges.

    The convex lens converges a parallel beam of light on refraction and is, therefore, also known as a *converging lens*. On the other hand a concave lens diverges a parallel beam of light on refraction and is, therefore, also called a *diverging lens*.

12. *Convex lens*. (*i*) has a real focus

    (*ii*) produces real and inverted images when the object is further from the lens than the focus. When the object is nearer to the lens than the focal length, an erect, virtual, and magnified image is obtained.

    Concave lens. (*i*) has a virtual focus

    (*ii*) produces an erect, virtual and diminished image of an object, and

    (*iii*) A virtual object may produce a real image

13. *Image formation* (*Graphical method*). In accurate drawing of images with both types of lenses, (*a*) the lens is represented thin, (*b*) a ray through the centre of the thin lens (*i e.*, optical centre) passes straight through the lens, (*c*) a ray parallel to the principal axis is refracted through the focus.

14. *Principal foci*. A lens has two principal foci ; a beam parallel to the principal axis incident on the left side of the lens is refracted through one focus (called the "second principal focus"), whilst a similar beam incident on the right side of the lens is refracted through the other focus (called the "first principal focus").

15. *Lens formulae* :

    (*i*) *New cartesian sign convention* :

$$\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$$

    (*ii*) For a convex lens ; f is $+$

    For a concave lens ; f is $-$

(*iii*) The linear magnification, $m=\frac{v}{u}=1-\frac{v}{f}$

16. The focal length of a lens depends upon the refractive index of the material from which it is made and the curvatures of the two surfaces. More the curvature, shorter the focal length.

17. *Power* (p) of a lens is the reciprocal of its focal length (f)

$$p=\frac{1}{f}$$

If the focal length is measured in *metres*, the power of the lens is in **dioptres**.

If we take a number of thin lenses and place them in close contact, then the power of the combination p is the algebraic sum of powers of the individual lenses, *i.e.*,

$$p=p_1+p_2+p_3+\ldots.$$

18. **The eye**. This contains (*i*) a crystalline lens, (*ii*) ciliary muscles which control the radii of the lens surfaces and hence the focal length, (*iii*) the retina, a sensitive "screen" at the back of the eyeball, covered with nerves linked to the optic nerve. The iris of the eye is a diaphragm with a circular (black) hole in the middle called the pupil ; the colour of an eye is the colour of the iris. The aqueous humour is a weak salt solution in front of the lens ; the vitreous humour is a gelatinous substance between the lens and retina. The cornea is the tough transparent spherical bulge in front of the lens.

The use of two eyes gives a three-dimensional view, bringing with it a sense of distance.

19. **Far and Near Points** : *Accommodation*. A person with normal vision can see clearly objects a very long way off. The *far point* of a normal eye is thus "infinity".

The nearest point which the eye can see distinctly is about 25 cm for normal vision. The distance concerned, D, is called the *least distance of distinct vision* of the eye.

With normal vision, the eye is fully relaxed or "unaccommodated" when viewing objects at infinity. When the object is at the least distance of distinct vision and is focused by the eye, the ciliary muscles are fully strained and the eye is said to be "fully accommodated".

20. *Myopia* or *Shortsightedness*. In this defect the far point is near the eye, and rays from infinity now come to a focus in front of the retina.

Correction is made by a *diverging* lens, whose focal length is equal to the distance of the far point from the eye.

Hypermetropia or *Far sightedness*. In this defect of vision, the far point of the eye is normal, but the near point is further from the eye than 25 cm.

Correction is made by a suitable *converging lens*.

21. A *microscope* magnifies the image of an object enabling us to study its details which are too small to bs seen by naked eyes.

Linear magnification (m) of a *simple microscope* or magnifying glass is given by

$$m=1+\frac{D}{f}=1+\frac{25}{f}$$

where D is *numerically* the least distance of distinct vision and f is the focal length.

22. *Compound microscope*. This has two converging lenses, both of short focal length. In using the instrument,

(*i*) the object is placed slightly *further* from the objective than its focal length ;

(*ii*) the real image formed is viewed through the eye piece, acting as a magnifying glass.

The magnifying power or magnification $m=m_{\text{objective}}\times m_{\text{eye piece}}$. It is the product of the magnifying powers of the objective and the eye piece.

23. *Astronomical Telescope*. It is a device for viewing distant objects. It consists of two converging lenses. The one which receives the light from the object is called the *objective*, the other lens through which we view the object is called the *eyepiece*.

When the final image is at infinity, the telescope is said technically to be in *normal adjustment*.

The magnifying power of the telescope, in normal adjustment, is given as

$$m=\frac{\text{Focal length of the objective}}{\text{Focal length of the eye piece}}=\frac{F}{f}$$

The distance between the lenses $= F+f$

Astronomical telescope. Final image at near point. The final image is now virtual and distant D from the eye piece; the image produced by the objective is thus nearer to the eye piece than its focal length.

24. The splitting of a beam of white light into different components when it passes througn a transparent medium, such as a glass prism, is called *dispersion* of light. The refractive index of a given material depends on the spectral colour of light.

25. *Rainbow* is a display of colours that occurs just after rain when the sun is shining. There are innumerable tiny droplets of water in the atmosphere and each of these split the sunlight into its spectrum which forms a rainbow.

26. An opaque object reflects certain colours and absorbs the rest. A red rose in the day time appears red because it reflects red light and absorbs other colours.

    Similarly, the colour of light in which we view an object also affects the colour of that object. For example, a red rose when illuminated by blue light would appear black as there is no red light to be reflected by the rose.

27. Light exhibits all the properties of a transverse wave. Light travels in vacuum as well. Light is an eletromagnetic wave. It shows interference; diffraction and polarization. Unlike sound, the wavelength of light is extremely small, about 6×10^{-7} m. This accounts for the difficulty in our observing the phenomena of interference and diffraction of light.

    The colour of thin films, like those of soap bubbles or soap films and of oil films on water is due to interference of light.

QUESTIONS

[A] Objective Type Questions

1. Complete the following sentence :

   When a ray of light is going from a less dense medium into a denser medium, it is bent ....the normal but when it is going from a denser medium into a less dense one it is bent............the normal.

2. Using Fig (6.44) the refractive index n of the transparent rectangular block is

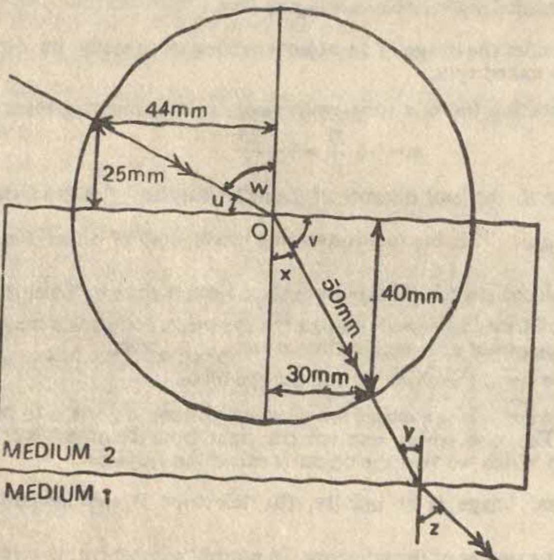


Fig. 6.44.

(i) $\dfrac{\sin w}{\sin z}$

(ii) $\dfrac{\sin x}{\sin w}$

(iii) $\dfrac{\sin u}{\sin v}$

(iv) $\dfrac{\sin u}{\sin x}$

(v) $\dfrac{\sin w}{\sin x}$

3. Which of the following statements is *not* true for Fig. (6.44) ?
   - (*a*) for glancing incidence, the refracted ray bends towards the normal ;
   - (*b*) the angles of incidence and refraction always have different values ;
   - (*c*) the emergent ray is always parallel to the incident ray.
   - (*d*) the light travels at a slower speed in medium 2 than in medium 1.
   - (*e*) the incident ray, the refracted ray and the normal at the point of incidence all lie in the same plane.

4. Refer Fig. (6.44). Which of the following statements is true ?
   - (*a*) the light waves have different wavelengths in both medium 1 and medium 2.
   - (*b*) the light waves have different frequencies of vibration in medium 1 and medium 2.
   - (*c*) all of the light incident on the point *O* enters the block and is bent towards the normal.
   - (*d*) the ratio of the angle of incidence to the angle of refraction is a constant.
   - (*e*) medium 2 is optically less dense than medium 1.

5. Using the dimensions given in the diagram, Fig. (6.44), the refractive index of the block is
   - (*a*) 1·66
   - (*b*) 1·60
   - (*c*) 1·50
   - (*d*) 1·47
   - (*e*) 1·33

6. The critical angle i_c for the medium 2 (Fig. 6.44) is
   - (*a*) 48° 45′
   - (*b*) 42° 52′
   - (*c*) 41° 49′
   - (*d*) 38° 41′
   - (*e*) 37° 3′

7. A red apple and a blue flower on a green stalk are placed in a dark room and then illuminated with light coming from a yellow filter. The appearance of the articles will be

	apple	*flower*	*stalk*
(*a*)	yellow	yellow	yellow
(*b*)	black	green	blue
(*c*)	green	blue	red
(*d*)	red	black	green
(*e*)	blue	red	black

8. A cross × is marked on a piece of paper and is then viewed *normally* through a glass cube placed on top of it. The cross will appear

(*a*) distorted horizontally
(*b*) displaced vertically downward
(*c*) displaced vertically upwards
(*d*) deviated slightly to the right
(*e*) deviated slightly to the left

Select the best answer.

9. The refractive index n of a medium can sometimes be expressed as

(*i*) $n = \dfrac{\text{speed of light in the medium}}{\text{speed of light in vacuum}}$

(*ii*) $n = \dfrac{\text{real depth}}{\text{apparent depth}}$

(*iii*) $n = \dfrac{\sin i}{\sin r}$

Decide which answer (s) is (are) correct and then choose from the following :

(*a*) (*i*) only is correct
(*b*) (*iii*) only is correct
(*c*) (*i*) and (*ii*) are correct
(*d*) (*ii*) and (*iii*) are correct
(*e*) (*i*), (*ii*) and (*iii*) are correct.

10. A person with defective vision can only accommodate over the range of 20 cm to 400 cm from his eyes. This person is suffering from

(*a*) myopia (short sight)
(*b*) hypermetropia (long sight)
(*c*) a combination of myopia and hypermetropia
(*d*) lack of accommodating power

11. The most suitable correcting lenses for the person in Q. (10) would have a power, in dioptres (m^{-1}) of

(*a*) −4·00
(*b*) −0·25
(*c*) +0·25
(*d*) +1·00
(*e*) +4·00

12. A long-sighted person cannot see clearly objects nearer to his eye than 50 cm. To enable him to read a book 25 cm away, he should use spectacle lenses whose power in dioptres (m^{-1}), is

(*a*) −6
(*b*) −4
(*c*) −2
(*d*) +2
(*e*) +4

13.

Assertion		**Reason**
A short-sighted person whose far point is 50 cm from his eyes needs a diverging spectacle lens of focal length 50 cm.	because	his unaided eye tends to form an image of a distant object behind the retina.

Answer

(*a*) if both assertion and reason are true statements and the reason is a correct explanation of the assertion.

(*b*) if both assertion and reason are true statements but the reason is *not* a correct explanation of the assertion.

(*c*) if the assertion is true but the reason is a false statement

(*d*) if the assertion is false but the reason is a true statement

(*e*) if both assertion and reason are false statements.

14. Convex lenses always

(*a*) have two spherical surfaces
(*b*) are thinner in the middle than at the edges
(*c*) are thicker in the middle than at the edges

15. An object is more than one focal length away from a converging lens. As the distance of the object from the lens increases the distance of the image from the lens

(*a*) increases
(*b*) decreases
(*c*) remains the same

16. In question (15), the size of the image

(*a*) increases
(*b*) decreases
(*c*) remains the same.

17. When a person uses a convex lens as a simple magnifying glass, the object must be placed at a distance from the lens of

(*a*) a little less than one focal length
(*b*) a little more than one focal length
(*c*) a little less than two focal lengths
(*d*) a little more than two focal lengths

18. The image produced by a concave lens is

(*a*) always virtual and enlarged
(*b*) always virtual and reduced in size
(*c*) always real
(*d*) sometimes real, sometimes virtual.

19. Real images formed by single convex lenses are always

(*a*) on the same side of the lens as the object
(*b*) inverted
(*c*) erect
(*d*) smaller than the object.

20. A virtual image is formed by
(*a*) a slide projector
(*b*) the ordinary camera
(*c*) a simple microscope.

21. A convex lens produces a virtual image. The distance of the object from the lens
(*a*) must be less than one focal length
(*b*) may be more than two focal lengths
(*c*) may be between one and two focal lengths
(*d*) must be two focal lengths.

22. An object is placed 12 cm from a convex lens whose focal length is 10 cm. The image must be
(*a*) virtual and enlarged
(*b*) virtual and reduced in size
(*c*) real and reduced in size
(*d*) real and enlarged.

23. An object is placed 20 cm from a concave lens whose focal length is 10 cm. The image must be
(*a*) virtual and enlarged
(*b*) virtual and reduced in size
(*c*) real and reduced in size
(*d*) real and enlarged.

24. An object is placed 25 cm from a convex lens whose focal length is 10 cm. The image distance is .... cm.

25. If the object in Q. (24) is 4 cm tall, the height of the image is .... cm.

26. The distance of an image from a convex lens is the same as that of the object. The distance of the object from the lens
(*a*) must be less than one focal length
(*b*) may be more than two focal lengths
(*c*) may be between one and two focal lengths
(*d*) must be two focal lengths.

27. The pupil in the eye corresponds to the .... in the camera.

28. A camera is used to photograph a distant object. If the focal length of the lens is f, the distance of the film from the lens should be
(*a*) slightly more than $2f$
(*b*) slightly less than $2f$
(*c*) slightly more than f
(*d*) slightly less than f.

29. The distance of distinct vision for a normal eye is
(*a*) 25 cm
(*b*) 25 m
(*c*) 0·25 cm
(*d*) 2·5 cm

30. A convex lens has a focal length of 20 cm. Its power in dioptres is
   - (*a*) 2
   - (*b*) 5
   - (*c*) 0·5
   - (*d*) 0·2

31. An optical instrument in which eye-piece used in a concave lens is
   - (*a*) An astronomical telescope
   - (*b*) A Galilean telescope
   - (*c*) A Compound Microscope
   - (*d*) A slide projector
   - (*e*) A Simple Microscope.

32. Myopia is corrected by using
   - (*a*) a convex lens
   - (*b*) a concave lens
   - (*c*) a plane mirror
   - (*d*) a convex mirror
   - (*e*) a concave mirror

33. The objective of a compound microscope is a
   - (*a*) Convex lens with large aperture and large focal length than eye-piece
   - (*b*) Convex lens with a small aperture and small focal length than eye-piece
   - (*c*) Convex lens with a small aperture and large focal length than eye-piece.

34. The power of a lens is $-5D$, its focal length is
   - (*a*) 2·0 m
   - (*b*) $-0·2$ m
   - (*c*) 20·0 m
   - (*d*) 5 m

[B] Very Short Answer Questions :

1. What is a convex lens ?
2. Does a concave lens produce the same type of image as a convex lens ?
3. What happens to a ray of light when it passes through the optical centre of a lens ?
4. What type of image is formed by a converging lens when the object lies between t principal focus and the optical centre of the lens ?
5. What is the nature of the image formed by a diverging lens ?
6. What is power of a lens ?
7. What is the power of a glass plate ?
8. What is the position of near point for a normal eye ?
9. What is the position of far point for a normal eye ?
10. What is the expression for the magnifying power of a simple microscope ?
11. An optician has lenses of power

$$X=+5D$$
$$Y=-5D$$
$$Z=-0·5D$$

Which one has maximum focal length ?

12. An old woman is advised to use lenses of power $+2{\cdot}5D$. What defect of vision is she suffering from ?

13. A 12 year old boy is unable to see a tree beyond a distance of 400 cm, but can see the nearby objects very well. What is this defect of vision called ? What is his far point ?

14. Does light travel faster in air or in water ?

15. Suppose light is travelling from water into glass, in what direction will it be bent ?

16. Define refractive index.

17. What is refraction of light ?

18. Define dispersion of white light.

19. What is spectrum of white light ?

20. What will a red flower look like in yellow light ?

21. Define critical angle.

22. Mention one major use of "fiber optics".

23. Why is it difficult to observe the phenomena of interference and diffraction for light ?

24. Does light travel in vacuum ?

25. Is light an electromagnetic wave ?

26. Power of 1st lens is 4 dioptres and that of the 2nd lens is -10 dioptres. What is the power of the combination ?

27. What is a light pipe ?

28. Out of two convex lenses of focal length 100 cm and 15 cm, which one will you prefer for using as a simple microscope ? [**Hints** : One of $f=15$ cm.] [*A.I.S S 1987*]

[C] Short-Answer Type and Essay-Type Questions:

1. (*a*) What is a lens ?

   (*b*) What is the difference between a convex lens and a concave lens ?

   (*c*) Define : Principal axis ; optical centre ; principal focus and focal length of a lens. Give diagram to illustrate your answer.

2. Derive the lens formula

$$\frac{1}{v}-\frac{1}{u}=\frac{1}{f}$$

where the symbols have their usual meanings.

Mention the assumptions and sign conventions used.

3. Define magnification produced by a lens and derive an expression for it in the case of (*i*) convex lens and (*ii*) concave lens.

4. Discuss the size, position and nature of the image formed by convex lens when the object lies

   (*i*) at infinity

   (*ii*) beyond $2f$ where f is the local length of the lens

   (*iii*) at $2f$

   (*iv*) between f and $2f$

   (*v*) at f

   (*vi*) between the optical centre and focus.

5. Discuss the size, position and nature of the image formed by a *concave lens* when the object lies

   (*a*) at infinity

   (*b*) at *f* where *f* is the focal length.

6. (*a*) Describe the construction of human eye. Draw labelled diagram.

   (*b*) Compare human eye with photographic camera.

7. What are the two main defects of vision ? How are they corrected ? (*A.I.S.S.E. 1982*)

8. (*a*) What is a microscope ?

   (*b*) When does a convex lens act as a simple magnifying glass (or simple microscope) ? Derive an expression for its magnifying power. Define magnifying power of a microscope.

   (*c*) What is the difference between a simple miscroscope and a compound microscope ?

9. (*a*) What is a telescope ?

   (*b*) Describe the working of an astronomical telescope. What features make its magnifying power large ?

10. **Explain** :

    (*a*) If you were supplied with four convex lenses of focal lengths 100 cm ; 25 cm ; 3 cm and 2 cm respectively, state which lenses you would select for constructing

    (*i*) an astronomical telescope,

    (*ii*) a simple microscope,

    (*iii*) a compound microscope ?

    (*b*) What alteration in the astronomical telescope is required to increase

    (*i*) magnification,

    (*ii*) brightness of image ?

11. (*a*) Name the Scientific terms which denote the following :—

    (*i*) The power of the eye which enables it to focus objects at varying distances away.

    (*ii*) Defect of the eye due to which a person cannot see the distant object clearly.

    (*iii*) Sensitive screen in the eye for the reception of images.

    (*iv*) The point for which the eye is focussed when at rest.

    (*v*) The nearest point to the eye at which a small object can be clearly seen.

    (*vi*) The distance of the point from the eye at which we can see objects most clearly.

    (*b*) State the Physical principle made use of in the case of *Magnifying* glass.

    (*c*) Answer the following questions :—

    (*i*) Is the image on the retina of the eye real or virtual ?

    (*ii*) What is circular aperture of the eye called ?

    (*iii*) In hypermetropia does the crystalline lens become more divergent or more convergent ?

    (*iv*) What is normally the distance of distinct vision ?

12. Which of the following, as normally used, form real images :
    - (*i*) eye
    - (*ii*) microscope
    - (*iii*) plane mirror
    - (*iv*) concave shaving mirror.

13. Show that a real image formed by a man by a converging lens only inverts him but that he and his image still have the same right hand. Show that exactly the reverse is true for an image formed by a plane mirror.

14. (*a*) What is refraction of light ?

    (*b*) State the laws of refraction of light ?

    (*c*) Define refractive index. How will you measure it for a glass slab ?

15. Show that if a ray of light is incident normally on a glass slab, it will pass undeviated.

16. Why does a water tank appear less deep than it really is ? What is the relationship between its real and apparent depths ?

17. Describe the image formation in a compound microscope.

18. Draw a diagram showing the path of a ray of light through a parallel-sided glass block. Label the following :

    Incident ray, refracted ray, emergent ray, normal, angle of incidence, angle of refraction and angle of emergence.

19. Explain with the help of a diagram why a stick appears bent in water.

20. What is Snell's Law ? What is meant by the index of refraction ? How does the speed of light wave in a medium affect the amount of refraction of light wave ?

21. (*a*) What does it mean to say that one substance is optically denser than another ?

    (*b*) What is the path taken by light which enters a triangular glass plate ?

22. Would our day-to-day life be changed much if light travelled slower in vacuum than in other materials ?

23. Some fishermen claim that it is better to lie flat (*i.e.* sleep) near the edge of the stream than to stand erect when fishing. Is there any fish-catching merit to such a statement ?

24. An object, which is under water does not appear to be as far below the surface as it really is when one looks at it from above the water. Explain why this is true ?

25. (*a*) What is "total internal reflection" of light ? [*A.I.S S. 1987*]

    (*b*) Mention the conditions for the total internal reflection of light to take place ? [*A.I.S.S. 1987*]

    (*c*) What is critical angle ? How is it related to the index of refraction ?

26. On warm sunny days tarmac roads often appear to be covered with pools of water some distance ahead, which disappear when approached. How do you explain this ?

27. (*a*) What property of a transparent substance causes the refraction of light rays which strike it at an oblique angle ?

    (*b*) What practical use is made of the index of refraction of a substance ?

28. Explain why we see the sun before it actually rises above the horizon in the morning and why we see it after it has dropped below the horizon in the evening.

29. You are looking diagonally down at a fish in a pond. To the fish, assuming that it can see you, does your head appear higher or lower than it actually is ?

30. Which is the better reflector of light—a right-angle prism or a plane silvered mirror ? Explain.

31. Why is a diamond more brilliant than a glass imitation cut the same way ?

32. Why are totally reflecting prisms usually designed so that light enters and leaves the prism at an angle of 90° with respect to the surface ?

33. (*a*) What is a light pipe ? On what principle does it work ? Mention one major use of such a device.
    (*b*) What is the name given to a new area of study which is based on this principle ?

34. Write a short note on "light as waves".

35. What name is given to the splitting of light into various colours by a prism ? What causes this splitting ?

36. Show in a diagram why a parallel-sided glass block does not split white light into the colours that make it up.

37. (*a*) Explain why one book appears red to the eye, and another green.
    (*b*) Explain why a book appears red when seen through a red transparent piece of glass but black when seen through a green one.
    (*c*) How is rainbow formed ?

38. Draw the ray diagram for an object seen through [*A.I.S.S. 1986*]
    (*a*) a simple microscope
    (*b*) a compound microscope [*A.I.S.S. 1987*]
    (*c*) an astronomical telescope.

39. How does a normal eye see clearly objects at various distances ? Name one of the common defects of vision and type of the lens used to remove it. [*A.I.S.S. 1987*]

PROBLEMS

1. (*a*) A ray of light in air is incident at 45° on the surface of some water. Find the angle of refraction in the water. Use $n=1\cdot33$.
   (*b*) A ray of light is incident at 45° on the surface of oil, $n=1\cdot55$, which is floating on water. Find the angle of the ray from the normal line in the oil and in the water. **[Ans.** (*a*) 32·1° (*b*) 27·1° in oil, 32·1° in water]

2. Calculate the critical angle for total reflection of a ray in glass, $n=1\cdot517$, in contact with water, $n=1\cdot333$. **[Ans.** 61·5°]

3. Refractive index of glass is 1·6. If light is incident on the glass slab at an angle of incidence of 60°, what will be the angle of refraction ? **[Ans.** 32·77°]

4. Light passes at an angle of incidence of 45° from water into air. What is the angle of refraction ? Take index of refraction of water with respect to air as 4/3. **[Ans.** 70·5°]

5. A water tank appears to be 1·2 m deep when seen from outside. What is its real depth ? The refractive index of water is 1·33. **[Ans.** 1·60 m]

6. Find the critical angle for total internal reflection for light travelling from (*i*) water into air and (*ii*) glass into water. $^an_w=1\cdot33$ and $^an_g=1\cdot6$. **[Ans.** (*i*) 49° (*ii*) 56·1°]

7. Two lenses, one of focal length 25 cm (a convex lens) and another of focal length −10 cm (a concave lens) are placed in contact. What is the (*i*) power of the combination and (*ii*) focal length of the combination ? What type of lens the combination acts ? **[Ans.** (*i*) −6 dioptres ; (*ii*) −16·67 cm ; concave lens]

8. An optical fiber consists of an interior glass fiber of index of refraction $n_1=1{\cdot}65$ coated with a thin layer of glass of index of refraction $n_2=1{\cdot}40$.

What is the critical angle for total reflection of a ray inside the fibre ? [**Ans.** 32°]

9. A microscope is arranged vertically above a beaker and focussed on a scratch at the bottom of the beaker. When hydrogen disulphide is poured in to a depth of 50 mm, the microscope must be moved up 23·5 mm to refocus the scratch. Calculate the refractive index of hydrogen disulphide. [**Ans.** 1·89]

10. A rectangular block of glass 30 mm thick and of refractive index 1·50 is separated by a uniform thickness of 10 mm of air from a rectangular block of plastic of thickness 24 mm and refractive index 1·60. What is the apparent displacement of an object which is viewed normally through the combination ? [**Ans.** 19 mm]

11. A small fish is in a river 0·8 m below the water surface and 0·6 m from the vertical bank. The surface of the water is level with the flat ground on the bank. How near to the edge of the river is a man, whose eyes are 1·5 m above ground, when can just see the fish ? Refractive index of water$=\frac{4}{3}$. [**Ans.** 2·0 m]

12. The refractive indices of glycerine and water are 1·46 and 1·33 respectively. What is the critical angle when the ray passes from glycerine to water ? [**Ans.** 65·5°]

13 In an experiment to find the refractive index of a glass block, a ray was shone on to the block at grazing incidence (that is, $i=90°$) and was found to enter the glass block at an angle of 40° 11′ with the normal. What was the refractive index of the block ? [**Ans.** 1·55]

14. Calculate the critical angle for diamond, its refractive index being 2·42. Why does diamond sparkle ? [**Ans.** 24·5°]

15. Suppose that the distance from the eye lens to the retina is 2 cm. What is the focal length of the eye lens system in viewing a distant object ? An object is at the normal near point ? [**Ans.** 2·0 cm ; 1·83 cm]

16. What must be the focal length of the lens in a projector if the image is to be 10 times the size of the object when projected on a screen 5 m away ? [**Ans.** 45·5 cm]

17. In a simple box camera the distance from the lens to the film is 0·1 m. If the focal length of the lens is 9·50 cm, where must an object be placed to give the best image on the film ? [**Ans.** 1·90 m from the lens]

18. A certain magnifying glass gives an image of the sun at a distance of 3·0 cm from the center of the lens. What is the approximate magnifying power of the lens ? [**Ans.** 8·33]

19. What is the magnifying power of an astronomical telescope having a 1·00 diopter objective and 30-diopter eye piece lens ? [**Ans.** 30]

20. A person whose distance of distinct vision is 14 cm uses a lens of 5 cm focal length to magnify a small object. What is the distance of the object when in focus and what magnification is obtained ? [**Ans.** 3·75 cm ; 4]

21. A short sighted student sees objects most distinctly at a distance of 15 cm. He wants to see a black board at a distance of three metres. What must be the nature of the lens he requires ? [**Ans.** Concave lens of local length of −15·8 cm]

22. A convex lens of 5 cm focal length is placed at a distance of 4 cm from an object Find the position and relative size of the image. [**Ans.** −20 cm ; 5 times the object]

23. It is required to throw an image magnified 29 times on a screen placed at a distance of 6 m from the object. Find the focal length and nature of the lens required. [**Ans.** 19·33 cm ; convex]

24 Find the distance at which an object should be placed in front of a convex lens of focal length 10 cm, to obtain an image of double of its size. **[Ans.** 15 cm]

25. An object is placed at a distance of 10 cm, in front of a concave lens of focal length 20 cm. Find the nature and position of the image formed by the lens.
[Ans. – 6·66 cm ; virtual and erect]

26. A convex lens forms an inverted and real image at a distance of 30 cm from its optical centre of an object placed at a distance of 80 cm from it. From the focal length of the lens. **[Ans.** 21·8 cm]

27. Find the position and the nature of the image of an object 5 cm high and 10 cm infront of a convex lens of focal length 6 cm. *[A.I.S.S. 1979]*
[Ans. 15 cm ; real ; 7·5 cm]

28. A small object is so placed infront of a convex lens of 5 cm focal length that a virtual image is formed at a distance of 25 cm. Find the magnification as well as the magnifying power. *[D.B.S.S. 1981]*
[Ans. 5, 6]

29. A lens has a power of $-2{\cdot}5\ D$. What is the focal length and nature of the lens. *[A.I.S.S.E. 1986]*
[Ans. – 40 cm ; concave lens]

30. The refractive index of a given medium with respect to air is 2. Find the critical angle for the medium. *[A.I.S.S. 1987]*
[Ans. 30°]

CHAPTER 7

Electricity

7.1. INTRODUCTION

Tremendous progress has been made since the days when the study of electricity was concerned mainly with static electricity and with current electricity turning motors and heating wires. The practical applications of electricity are numerous and well known. The object of this chapter is to introduce students to the study of static and current electricity in such a way that various phenomena observed in daily life and concerned with this aspect of nature can be understood.

The concepts of charge, field intensity and potential have been introduced in static electricity. The current as a flow of charges, resistance and potential difference are the three basic concepts which have been dealt with in current electricity. The sources of current—its various effects, simple circuits and their practical applications have also been discussed.

7.2. ELECTRIC CHARGE

It was discovered by Thales, about 600 B.C., that when amber was rubbed with flannel or catskin, it acquired the property of attracting light objects, such as pieces of paper, cork, etc., and it is from *electron*, the Greek word for amber, that the term electricity is derived. But, now we know that this property is shared by many other substances, such as glass, ebonite, sealing wax, etc. when they are rubbed under suitable conditions. A substance which exhibits this property is said to be *electrified* or *charged* and the mysterious agent, which causes this state of the body, is known as *static electricity*. A body, which does not possess this property, is said to be *neutral*.

Rub a glass rod with silk and place it in a stirrup, suspended by a silk thread. Now, rub another glass rod with silk and bring it near the charged end of the first by placing it in another stirrup suspended by another silk thread as shown in (Fig. 7.1). It will be seen that the suspended rods are *repelled* from each other. This force acts even when the two rods are some distance apart. It would still act if they were in a vacuum. If an ebonite rod is rubbed with flannel, its subsequent behaviour is different. Two ebonite rods so treated repel each other, just as two glass rods rubbed with silk do, but an ebonite rod rubbed with flannel attracts a glas rod rubbed with silk (Fig. 7.2).

The experiments show that there are *two kinds of electrical charges* ; one which is developed on glass when it is rubbed with silk and the other which is developed on the ebonite

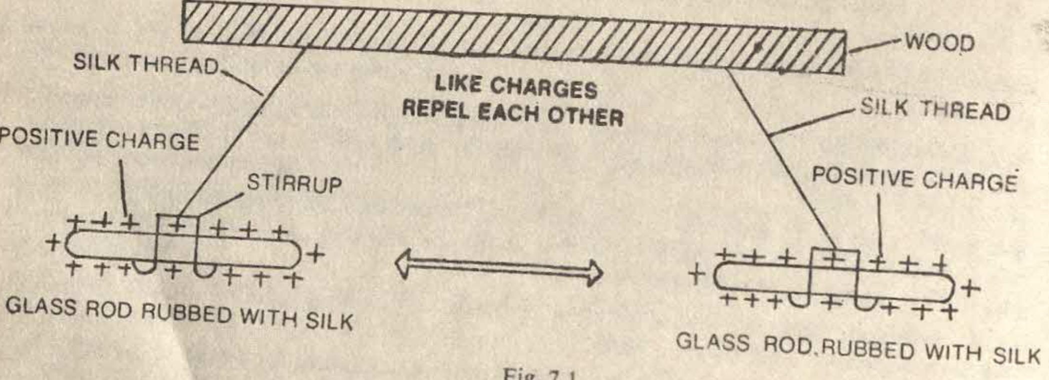


Fig. 7.1

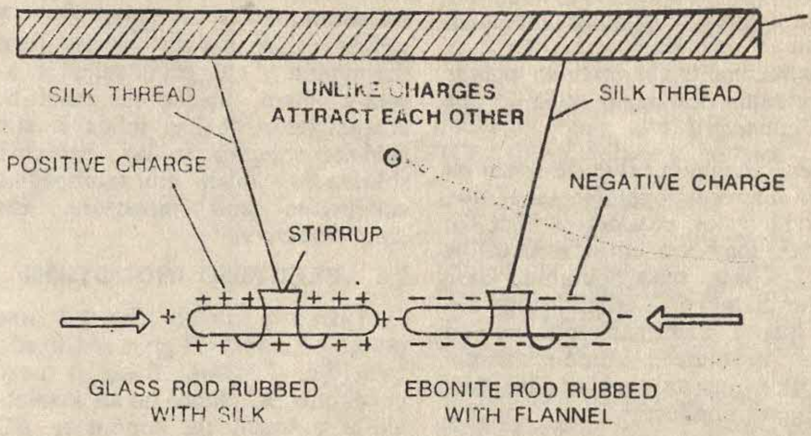

WOOD
SILK THREAD
UNLIKE CHARGES ATTRACT EACH OTHER
SILK THREAD
POSITIVE CHARGE
NEGATIVE CHARGE
STIRRUP
GLASS ROD RUBBED WITH SILK
EBONITE ROD RUBBED WITH FLANNEL

Fig. 7.2

rod, when it is rubbed with flannel. Historically the charge acquired by a glass rod after it is rubbed with silk was defined as **positive**. **Negative charge** was the one which an ebonite rod acquired on rubbing with flannel. These positive and negative conventions are purely arbitrary but nevertheless useful. We, thus, conclude that **like charges repel each other and unlike charges attract each other.** These forces act at a distance.

The fact is that every material, whether charged or not, already contains vast amount of electric charge. If it is electrically neutral, this is merely because the charge is there in exactly equal amounts of positive and negative. It is electrical force which holds the atoms together in a solid and every atom itself consists of positively charged nucleus with negatively charged electrons moving around it, held to the nucleus by electrical attraction. Charging processes (by rubbing) consist of transfer of electrons. When a glass rod rubbed with silk acquires a positive charge, this is because it surrenders some electrons to the silk, which consequently acquires equal negative charge. If you test the piece of silk with which the glass rod was rubbed by bringing it close to an ebonite rod rubbed with flannel, you will find the charge on the silk to be negative. Similarly the piece of flannel with which the ebonite rod is rubbed acquires positive charge. Detailed studies have shown that in each case the positive and negative charges produced by rubbing the two materials are *equal* in magniude. It is thus clear that the process of rubbing does not create electric charge. It esults in only transferring negative charges from one material to the other. The material from which the negative charges have been transferred is left with an excess of positive charge. The material which receives the negative charges becomes negatively charged. This is a typical example of a general principle that *electric charge is conserved. It can neither be created nor destroyed.*

7.3. CONDUCTORS AND INSULATORS

If we hold a piece of brass tube in one hand and rub it with flannel, no sign of electrification is produced ; but if we fix the brass tube on to an ebonite rod and rub it with dry flannel, taking care to avoid touching the brass tube with anything but flannel, we find that the brass tube is negatively charged. In the first case, the electric charge is certainly produced by friction but since the brass tube, the human body, and the earth are all connected, the electric charge spreads itself over the brass and passes through the human body on to the earth and so the brass shows no signs of electrification. In the second case also, the electric charge is produced by friction but is prevented from passing to the earth by the ebonite handle and the tube thus remains charged. This shows that, with respect to the passage of an electric charge through them, substances can be divided into two classes : *conductors* and *insulators*.

A **conductor** *is a material through which an electric charge is readily transferred.* Most metals are good conductors. At normal temperatures, silver is the best solid conductor ; copper and aluminium follow in that order. Gold, human body and graphite are also important conductors. Solutions of inorganic salts in water are good conductors as well. Earth is regarded as one huge conductor. A body which is connected to the earth by means of conducting communication is said to be *earthed* or *earth connected.*

An **insulator** *is a material through which an electric charge is not readily transferred.* Good insulators are such poor conductors that for practical purposes they are considered to be non-conductors. Glass, mica, paraffin, hard rubber ; sulphur, silk ; shellac ; dry air, ebonite ; oils, quartz and many plastics are good insulators. Pure water is a non-conductor but ordinary water, on account of dissolved impurities, is a good conductor.

It should be noted that the difference between conductors and insulators, although sometimes very marked, is one of degree. No substance is so good a conductor as not to offer any resistance to the passage of an electric charge through it. On the other hand, no substance is a perfect insulator. For instance a glass rod will also allow the electric charge to flow along it if a *high electrical pressure* is applied at its ends. There are certain substances whose property of carrying charges lies between conductors and insulators. Such substances are cotton, dry wood, paper etc. The student should realize that the precise formulation of the motion of charges in solids is a very complex problem. In fact the exact behaviour of charges (electrons) in solids is still an active field for research to-day, particularly for the substances which are intermediate between conductors and insulators, the so-called *semiconductors.*

7.4. ELECTRIC INDUCTION

Take a positively charged brass sphere A, placed on a vertical glass rod fixed on a metal base [Fig. 7.3 (*a*)]. Bring it near a neutral conductor *BC* placed on an insulating stand. If we now touch the conductor *BC* at *C* by a hand [Fig. 7·3 (*b*)] and then remove first the hand and then the conductor A, on testing, the conductor *BC* is found to have got a negative charge, *i.e.*, it would repel negatively charged pith ball (Fig. 7.3) *BC* shows the presence of charge only **when the hand is removed first and the conductor A is removed afterwards.** *This is explained by the fact that the positive charge on A attracts negative charge and repels positive charge.* Thus the negative charge moves to the end *B* and

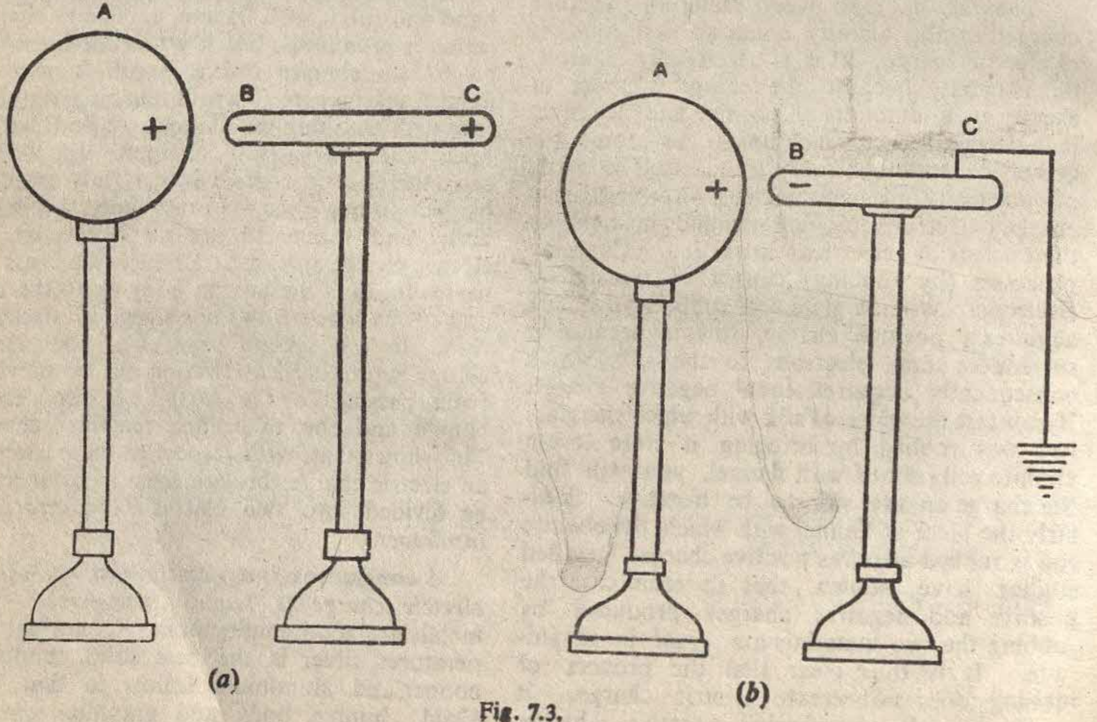


Fig. 7.3.

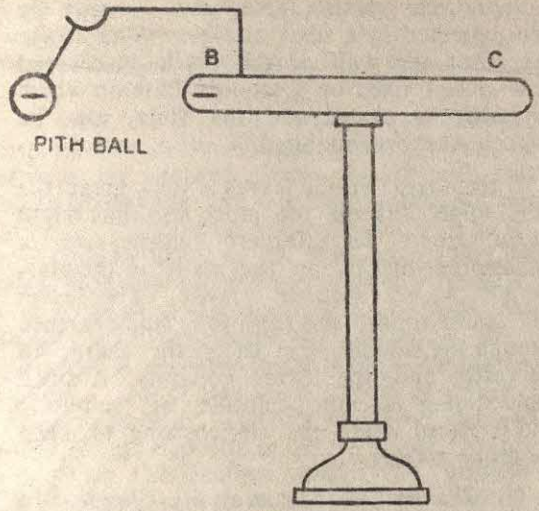


Fig. 7.3.

the positive charge moves to the end *C*. Here negative charge is **bound** at the end *B* by the positive charge on *A* and positive charge at end *C* is **free** and goes to the earth through our body when we touch it. When the hand is removed and then the conductor A, the negative charge *B* is no longer bound and, therefore, spreads on the whole surface of the conductor. Thus the conductor *BC* is negatively charged. **This phenomenon of charging a neutral conductor by bringing another charged conductor near it, is known as induction**. The charge induced in a neutral body is of the *opposite nature* to that o the charge body.

The quantity of charge induced on a neutral conductor increases (*i*) with the charge on the inducing body and (*ii*) with the decrease in the distance between the two.

Separation of Charges :

In the above experiment, let us replace the cylindrical conductor *BC* by two insulated spheres *B* and *C* as shown in |Fig. 7·4 (*a*)] and place them in contact with each other. Again bring a positively charged sphere *A* near *B*.

Negative charge will be induced on *B* and positive charge on *C*. Now separate the two spheres *B* and *C* [Fig. 7·4 (*b*)] while the sphere *A* is still in position and then take away the charged sphere A. If we test the two spheres with pith balls, it will be observed that a negatively charged pith ball is repelled by B, while a positively charged pith-ball is repelled by *C*. Thus the charges have got separated.

The neutral body can be given the same type of charge as that on the charged body if it is brought into contact with the latter. A part of the charge is then transfered from the charged body to the neutral body. This process of charging a body is known as CONDUCTION.

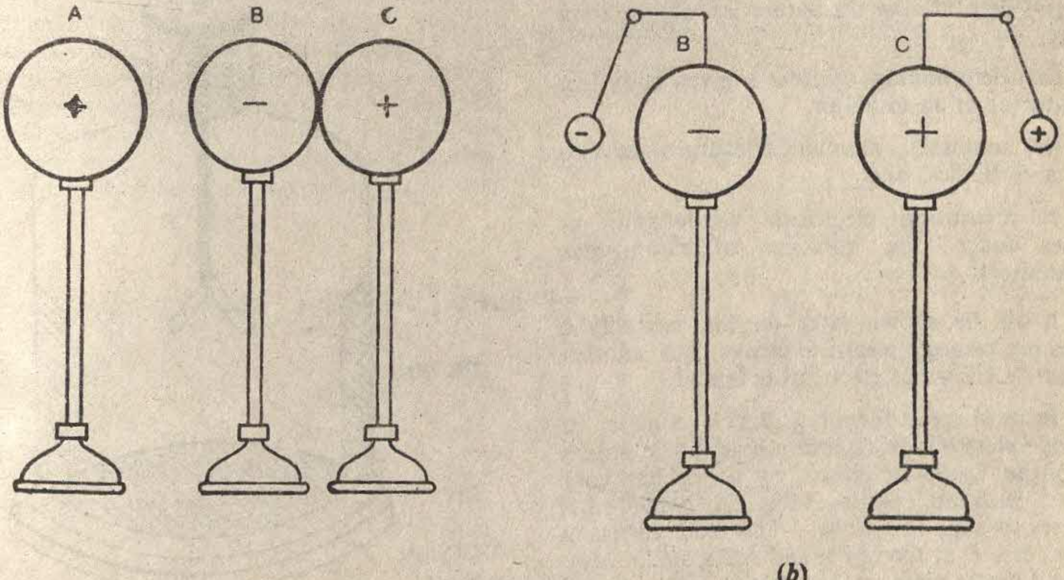


Fig. 7.4.

The two processes namely induction and conduction differ from each other in the following three ways :

(*i*) By induction the neutral body acquires the charge which is of opposite nature to the charge on the charged body and by conduction the neutral body acquires the same type of charge as that on the charged body.

(*ii*) During induction there is no loss of charge present on the charged body and during conduction, the charged body loses a part of its charge and thus the latter process of charging the bodies is very much limited in scope.

(*iii*) By induction the neutral body can be given as much charge as is present on the charged body provided certain suitable conditions are satisfied, but by conduction only a part of the charge can be given to the neutral body.

Michael Faraday in 1810 carried out a series of experiments and concluded that

(*a*) the induced negative and positive charges equal in amount and (*b*) inducing positive charge is equal to the induced negative charge.

Gold-leaf Electroscope : Gold-leaf electroscope is an instrument used for

(*i*) detecting the presence of charge on a body,

(*ii*) determining the nature of charge on a body,

(*iii*) determining whether a given body is a conductor or an insulator.

(*iv*) comparing amounts of charges on two or more bodies, and

(*v*) measuring electrical conductivity of gases under the influence of radio-active substances.

It will be shown later on that actually it does not measure electrical charge, but another quantity known as electrical potential.

In its simplest form (fig. 7.5) it consists of a wide glass bottle without a base. The mouth *N* of the bottle is closed by a rubber cork fitted with an ebonite tube. A brass rod *R* passes through this tube This rod carries a brass disc *D* at the upper end and a small horizontal brass piece at the lower end. A gold leaf is attached to each end of this brass piece. In the normal position these leaves lie side by side separated by a small distance. The lower portion of the wall of the bottle is covered with tinfoil fixed on a wooden base on which the bottle is placed and the foils can be earthed whenever required.

If the charge on the leaves is very great the leaves might diverge too much and thus might get ruptured. To safeguard against such a damage the tinfoils on the walls of the glass bottle provide a suitable remedy. The leaves touch these tinfoils and these foils being earthed through the wooden base carry the charge to the earth, and the leaves collapse. A small cup containg calcium chloride or sulphuric acid is placed inside the electroscope to keep the inside air dry.

(*i*) *Testing the Presence of Charge.* In order to test the presence of a charge on a body, we bring the body near the gold leaf electroscope. The divergence of the leaves shows that the body is charged either positively or negatively. A neutral body will have no effect on the gold leaf electroscope. If the body is charged *positively*, it induces a negative charge on the disc and the positive charge goes

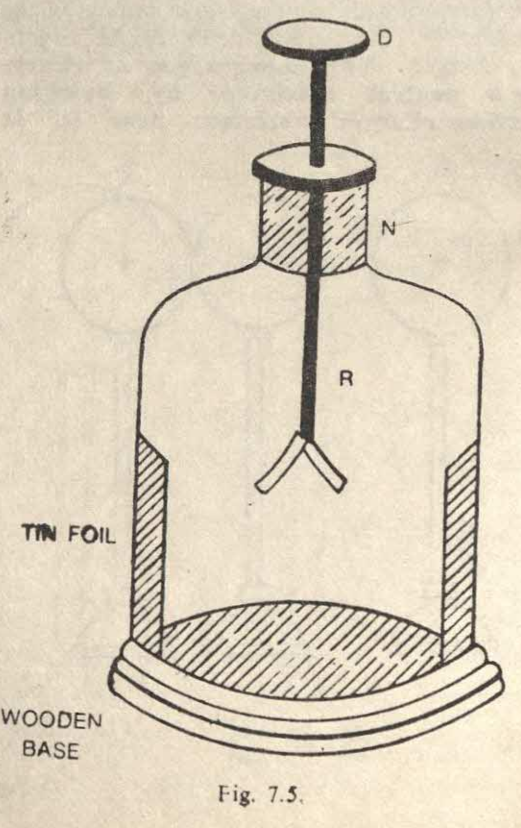


Fig. 7.5.

to the leaves. The leaves having the same charge repel each other. If the body is charged negatively there will again be a repulsion due to negative charge induced in them.

It must be noted that the leaves collapse again as soon as the charged body is removed away, as the induced charge on the disc is neutralised by the opposite charge induced on the leaves. The leaves also collapse if the disc is touched by hand, as the free charge on the leaves goes down to the earth through the body. Now if the hand is removed first and then the charged body, the leaves again diverge. This divergence is now due to the charge bound in the disc. This charge spreads over the rod and the leaves as well. Thus the leaves are charged with a charge opposite in nature to the charge present on the charged body. The goldleaf electroscope is said to be **charged by induction**. The procedure is explained diagramatically in fig 7·6.

If the charged body is brought into actual contact with the disc of the gold leaf electroscope, the leaves again diverge. This divergence is due to the charge which flows from the charged body through the disc and the rod. The gold-leaf electroscope is thus **charged by conduction**. This time it has the same type of charge as the charge on the charged body.

(*ii*) *To determine the nature of the charge.* In order to determine the nature of the charge present on a body, we charge a gold-leaf electroscope positively and bring the charged body near it. If the divergence of the leaves increases, the body is charged positively and if the divergence decreases the body is charged negatively. The nature of the charge can also be confirmed by charging a gold leaf negatively, when the opposite effect will be seen. It must be noted here that a neutral body also causes a decrease in the divergence of the leaves. That is why we say that repulsion or more repulsion is the sure test of presence of charge.

(*iii*) *To determine whether a given body is a conductor or an insulator.* Charge a gold-leaf electroscope positively or negatively. The leaves diverge. Hold the given body in the hand and touch the disc with the other end of the body. If the body is a conductor, the leaves collapse and if the body is on insulator, there is no change in the divergence of the leaves.

7.5. COULOMB'S LAW OF FORCE BETWEEN CHARGES :

We have seen that two similar charges repel each other and two dissimilar charges attract each other. The force of attraction or repulsion obeys the following law known as *coulomb's law of force between charges* due to Charles Coulomb (1736-1806). Coulomb's law states that the **force between two electric charges is proportional to the product of the charges and inversely proportional to the square of the distance in vacuum between them.**

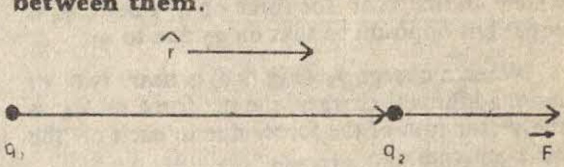


Fig 7.7

If a charge q_1 is at a distance r from a second charge q_2, then the force on q_2 (Fig. 7.7) is

$$\boxed{\vec{F}=K\frac{q_1q_2}{r^2}\hat{r}} \qquad \ldots(1)$$

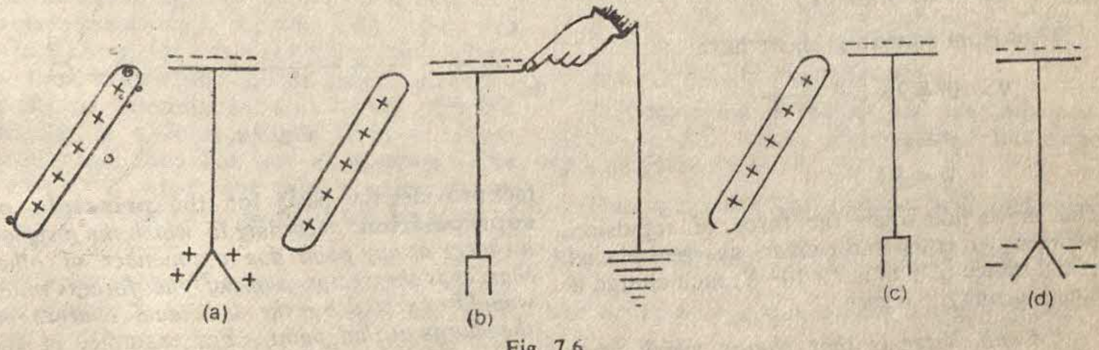


Fig. 7.6.

where $\vec{\hat{r}}$ is a unit vector directed towards q_2 and R is the constant of proportionality. In S.I. units, the charge is measured in coulombs, and K has the experimentally determined value

$$K=9.0\times10^9\ Nm^2C^{-2}$$

The force is attractive if q_1 and q_2 have opposite signs and it is repulsive if they have like signs. It is directed along the line joining the centres of the two charged bodies.

If we are interested only in the *magnitude* of the force of attraction or repulsion between two electric charges, then it will be given by

$$\boxed{F=K\frac{q_1q_2}{r^2}} \qquad ...(2)$$

where $K=9\times10^9\ Nm^2/C^2$ in S.I. units

Note that

$$\vec{F}_{12}=-\vec{F}_{21},$$

which shows tnat the force on q_1 due to q_2 is equal but opposite to that on q_2 due to q_1.

When a charge q_2 (Fig. 7.7) is near two or more additional charges, the net force on q_2 is the vector sum of the forces due to each of the other charges.

Unit Charge

Suppose we take two similar charges each equal to q and place them in vacuum (or air) at a distance of 1 m. If the force of repulsion between them is $9\times10^9\ N$, then for equation (2).

$$q_1=q_2=q$$
$$r=1\text{ m}$$
and
$$F=9\times10^9\ N$$

Thus from equation (2), we have

$$9\times10^9=9\times10^9\ \frac{q^2}{(1)^2}$$

or $$q^2=1$$

or $$q=\pm1$$

This shows that when the force of repulsion between two equal and similar charges placed at a distance of 1 m is $9\times10^9\ N$, each charge is equal to unity. Hence,

"*A unit charge is that charge which when placed in vacuum (or air) at a distance of one metre from a similar **and an equal charge repels it with a force of 9×10^9 newtons***". This is known as the **coulomb (C)**. **It is the unit of** electric charge in **S.I. units. Note that 1** coulomb is an enormous **charge. The ele**mentary unit of charge **used in atomic physics is charge** on an **electron *i.e.*** $1{\cdot}602\times10^{-19}$ coulomb. It is **interesting to note that 1** coulomb of charge **contains**

$$\frac{1}{1{\cdot}6\times10^{-19}}=6{\cdot}25\times10^{18}\text{ electrons.}$$

Frequently, it is **convenient to work with a** fraction of coulomb **called the *micro-coulomb*** (μC).

$$1\mu C=10^{-6}C$$

7.6. PRINCIPLE OF SUPERPOSITION :

A, *B* and *D* are three bodies carrying charges $+q_1$, $-q_2$ and $+q_3$ respectively as shown in Fig. 7.8. What is the force exerted by charges q_1 and q_2 on q_3? We first find the force on q_3 due to q_1 when q_2 is far away. Then we take q_1 away and bring q_2 in its original position and determine the force on q_3. Finally we measure the force on q_3 due to both q_1 and q_2 placed in their original positions. We find experimentally that the force on q_3 is equal to the *vector sum* of the forces previously measured. This shows that the force with which two charges interact is not affected by the presence of a third charge. This fact provides the basis for the **principle of superposition** *according to which the force on a charge at any point due to a number of other charges is the vector sum of the forces which would be exerted by the individual charges on the charge at that point*. For example, in the case of three charges shown in Fig. 7.8, the net force exerted by the charges q_1 and q_2

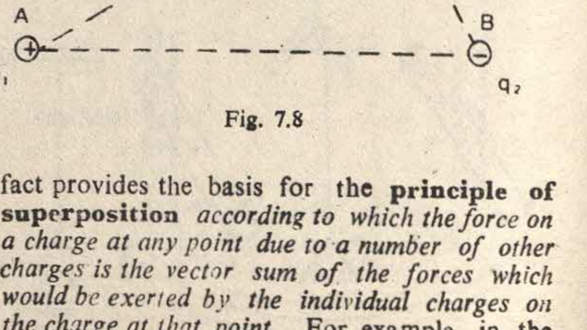


Fig. 7.8

on q_3 is the vector sum of the forces independently exerted by q_1 and q_3 on q_2 *i.e.*

$$\boxed{\vec{F}_3=\vec{F}_{31}+\vec{F}_{32}}$$

7.7. ELECTRIC FIELD

Electric forces, like the gravitational forces, act between bodies that are not in contact with each other. The proper way to regard such forces involves the concept of a **force field.** When a mass is present somewhere, the properties of space in its vicinity can be considered to be so altered that another mass brought to this region will experience a force there. The 'alteration in space' caused by a mass is called its gravitational field, and any other mass is thought of as interacting with a field and not directly with the mass responsible for it. Similarly an electric charge produces an **electric field** around it that interacts with any other charges present. *Thus electric field is the space surrounding a charged body within which its influence is felt.*

One reason it is preferable not to think of two charges as exerting forces upon each other directly is that if one of them is changed in magnitude or position, the consequent change in the forces each experiences does not occur immediately, but takes a definite time to be established. This delay cannot be understood on the basis of the Coulomb's Law, but is easily accounted for in terms of the field concept by assuming that the changes in the field travel with a finite speed *i.e.* the speed of light, 3×10^8 *m/s.*

If we place a point charge in an electric field some force acts on it. The magnitude of this force depends upon the strength of the electric field and the strength of the charge. To measure the strength of the electric field or the **electric intensity** at a point, we place *a unit positive charge* (or *a test charge*) at that point. The force experienced by this charge measures the electric intensity at that point. Electric intensity is a force; hence it is a **vector** quantity and thus has got a *direction.* The direction in which the unit positive charge moves when free to do so gives the direction of intensity. Hence.

"The intensity of the electric field at a point in an electric field is the force experienced by a unit positive charge placed at that point. The direction of the electric intensity is the direction in which the unit positive charge begins to move if free to do so.

We can use Coulomb's Law to determine the magnitude of the electric field surrounding a single charge q. We find the force F that q exerts upon a unit positive charge (*test charge*) at a distance r away, which is

$$\vec{F}=K\,\frac{q\times1}{r^2}\,\vec{\hat{r}}$$

where $\vec{\hat{r}}$ is a unit vector directed from the charge q towards the point where the test charge is located.

or $$\vec{F}=\frac{Kq}{r^2}\,\vec{\hat{r}}$$

where $K=9\times10^9$ Nm^2C^{-2}

This by definition is the electric field intensity $\vec{E}$ at a distance r from the charge q.

$$\boxed{\therefore\ \text{Electric field intensity}=\vec{E}=\frac{Kq}{r^2}\vec{\hat{r}}}$$

The *magnitude* of electric field intensity is given by

$$\boxed{E=\frac{Kq}{r^2}}$$

If q is *positive* $\vec{E}$ points along $\vec{\hat{r}}$ or away from q; if q is *negative* $\vec{E}$ points along $-\vec{\hat{r}}$ or toward q. *The electric field due to a charge points away from the charge if it is positive, and toward it if the charge is negative.*

It is expressed in *newton per coulomb i.e.* NC^{-1} in S.I. units. Electric field intensity falls off inversely as r^2.

Once we know the electric field intensity $\vec{E}$ at any point in an electric field, we can easily find the force $\vec{F}$ acting on any charge Q placed at a point *i.e.*

$$\boxed{\vec{F}=Q\vec{E}}$$

When there are several charges $q_1, q_2, \ldots$ at various positions, the electric field $\vec{E}$ at a point is the vector sum of the individual electric fields $\vec{E}_1, \vec{E}_2, \ldots$ due to all the charges.

7.8. ELECTRIC LINES OF FORCE

Let us consider a positively charged sphere isolated in space, $+Q$ of [Fig 7.9 (*a*)]. A small positive charge $+q$, which we shall call a *test charge*, is brought near the surface of the sphere. Since the test charge is in the electric field of the sphere and the charges are similar, it experiences a repulsive force directed radially away from $+Q$. Were the charges on the sphere negative, as in [Fig. 7.9 (*b*)], the force acting on the test charge would be directed radially toward $-Q$.

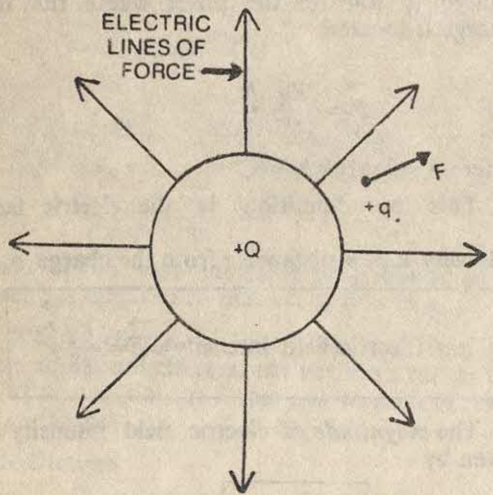


Fig. 7.9 (*a*)

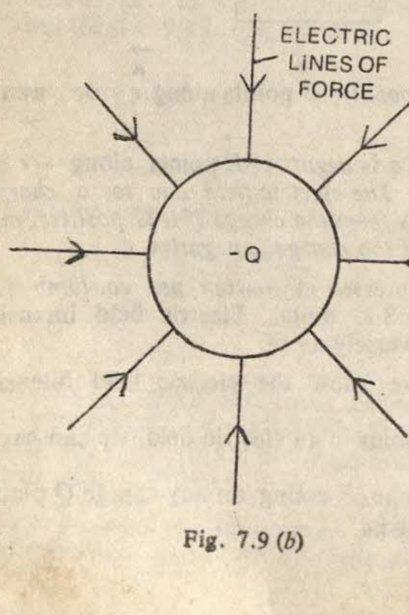


Fig. 7.9 (*b*)

An **electric line of force** *is a line so drawn that a tangent to it at any point indicates the orientation of the electric field at that point.* We can imagine a line of force as the path of a test charge moving slowly in a very viscous medium in response to the force of the field. By convention, electric lines of force *originate* at the surface of a positively charged body and *terminate* at the surface of a negatively charged body, each line of force showing the direction that a positive test charge would be accelerated in that part of the field. A line of force must therefore be *normal* to the surface of the charged body where it joins that surface.

The *intensity*, or strength of an electric field, as well as its direction, can be represented graphically by lines of force. *The electric field intensity is proportional to the number of lines of force per unit area normal to the field.* Where the intensity is high, the lines of force will be close together. Where the intensity is low, the lines of force will be more widely separated in the graphical representation of the field.

In Fig. 7.10 (*a*) electric lines of force are used to show the electric field near two equally but oppositely charged objects. At any point in this field the resultant force acting on a test charge. $+q$ can be represented by a vector drawn tangent to the line of force at that point.

The electric field near two objects of equal charge of the same sign is shown by the lines of force in [Fig. 7.10(*b*)]. The resultant force acting on a test charge $+q$ placed at the midpoint between these two similar charges would be zero.

The following properties are attributed to the electric lines of force :

(*i*) They start from the positive charge and end at the negative charge.

(*ii*) Two electric lines of force never intersect each other.

(*iii*) There are no electric lines of force inside a hollow conductor.

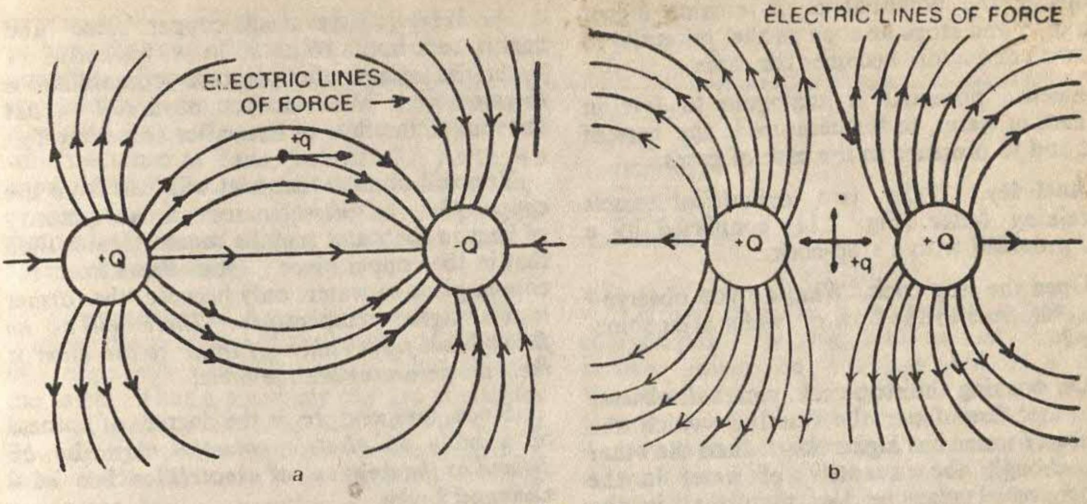


Fig. 7.10.

(*iv*) Number of electric lines of force per unit area gives a measure of the electric field intensity (extent of the influence of the charge) at a point in that area.

(*v*) They have the properties of longitudinal contraction and lateral repulsion.

These electric lines of force are all *imaginary* but they indicate the direction in which the electric field in the space is acting. They are very useful in explaining various electrical phenomena, *e.g.*, attraction between two unlike charges is explained by the property of longitudinal contraction ; repulsion between two like charges is explained by the property of lateral repulsion and electrical induction is explained by the fact that lines of force leaving a positive charge when fall on one end of a good conductor produce a negative charge there and these lines then flow through the conductor and leave it at the other end and charge it positively. If, however, the conductor is earthed, the inductive action does not travel forward.

7.9. ELECTRICAL POTENTIAL DIFFERENCE

When we raise a body from the ground to a certain height, we do a certain amount of work on the body. This increases its potential energy. Therefore a point at a higher level means a point of greater potential energy or a higher gravitational potential. Now we know that a body if left to itself falls down from a point of greater potential energy or higher gravitational potential to a point of lower gravitational potential. Similar is the case with electricity. Suppose we have two insulated conductors *A* and *B* charged positively. If we place them in contact or connect them by a wire, *charge* will flow from one conductor to the other. The direction of flow of charge depends upon the *electric condition* of the two conductors.

The electric condition of a conductor which determines the flow of electric charge from it to another conductor placed in contact is known as its **electrical potential.**

If the positive charge flows from conductor *A* to conductor *B*, then *A* is at a *higher* potential than *B*. The flow of charge continues

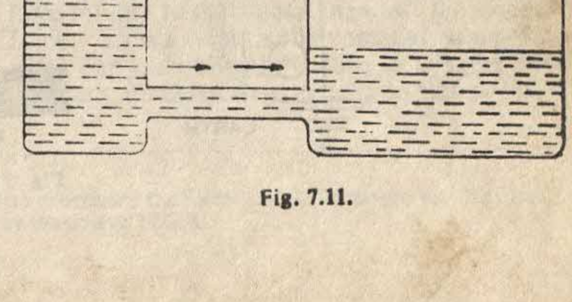


Fig. 7.11.

as long as the potential of *A* remains higher than of *B* and stops as soon as the potential of the two conductors becomes the same.

Electric potential is analogous to level in the case of water, to temperature in the case of heat and to pressure in the case of gases.

Activity. Take two cylindrical vessels containing water (Fig. 7.11) connected by a tube provided with a stop-cock.

Open the stop-cock. What do you observe ? What happens to the flow of water after sometime ?

On opening the stop-cock, you will observe that water flows from the vessel in which the surface of water has *higher level* than the other even though the quantity of water in the former vessel may be less than that in the latter. *There will be no flow if the levels are the same.*

Activity. Take small copper piece and heat it red hot. Place it in a bucketful of water at room temperature containing a thermometer. What do you observe ? What happens to the flow of heat after sometime ?

You will observe that heat will flow from the copper piece to the water, though the quantity of heat in the water may be much greater than that in the copper piece. Heat flows from the copper piece to water only because the former is at a higher temperature. *There will be no flow of heat from either of them to the other if their temperatures are the same.*

Since temperature is the degree of hotness of a body so *electric potential may also be defined as the* **degree of electrification of a charged body.**

Just as the height of a place is measured with respect to sea-level which is taken as *zero*

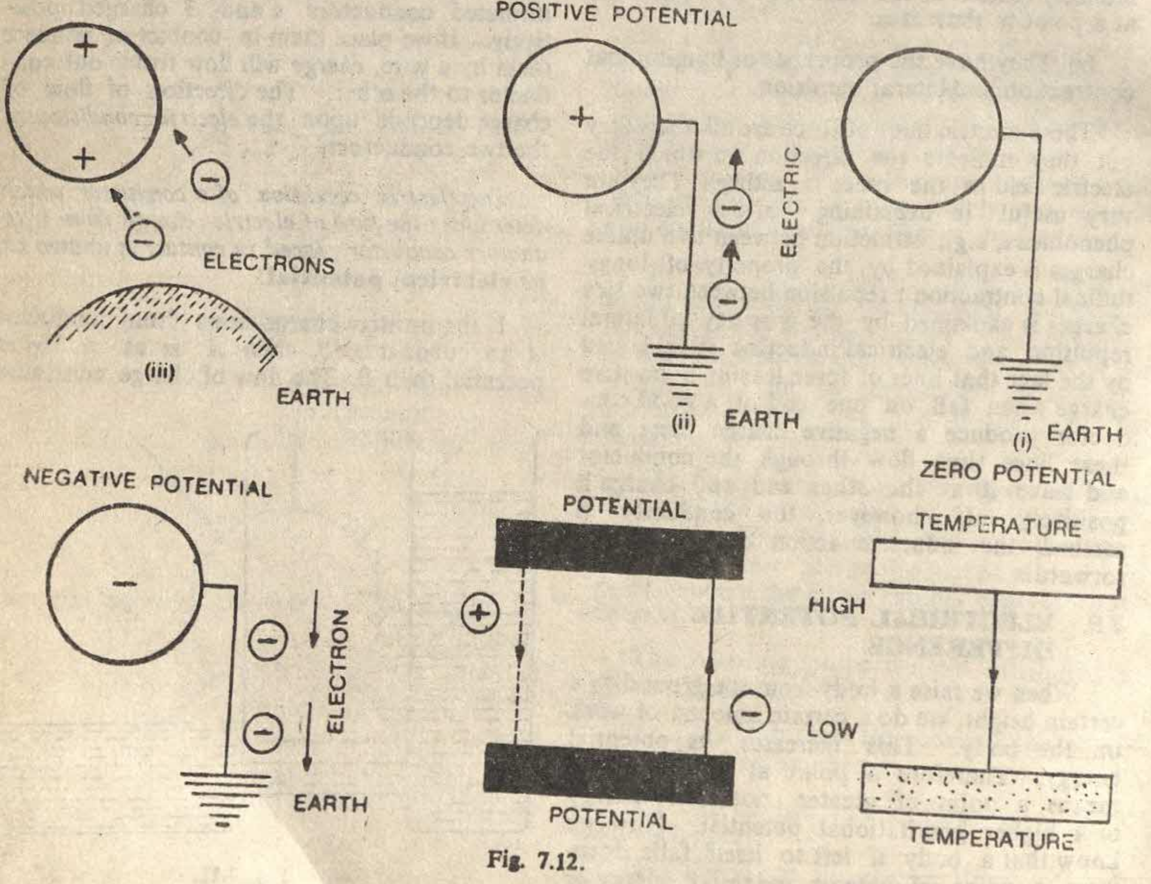


Fig. 7.12.

or a *standard level* (as its capacity for water is so huge that any addition or removal of a small quantity of water does not affect its level appreciably), the potential of a conductor is measured with respect to that of the earth which is taken at **Zero potential.** Earth is a good conductor of electricity and a *huge capacity* for *electric charge* and any addition or removal of a small charge would not alter its potential appreciably.

The potential of a *positively* charged body is *above* the potential of the earth and potential of a *negatively* charged body is *below* that of the earth. Thus a positively charged conductor has a *positive potential* as the positive charge flows from it to the earth (or the electrons flow from the earth to it) A *negatively charged* conductor has a *negative potential* as the positive charge flows from the earth to the conductor (the electron flow would be from the conductor to the earth). An earth connected conductor has **zero potential** [Fig. 7.12]. Potential at a point is a **scalar** quantity.

Unit of Potential—(volt).

We know that the difference of level is measured practically by means of measuring rods or tapes. There is, however, another purely theoretical method by which it is possible to measure difference of level, *viz* ; by considering the amount of work done in carrying a unit mass from one level to another. If a mass of *one kg* is carried through a height of *one metre* vertically, the work done is 9·8 joule; if to a height of 10 m, the work done is 98 joule ; if to a height of 50 m, the work done is 490 joule and so on Thus, knowing the amount of work expended on a unit mass, we can calculate the height through which it has been carried. *Hence, we can define the difference of level in terms of the work done in moving a unit mass from the lower to the higher level.* In other words, the difference in level can be measured by the difference of gravitational potential energy which the unit mass possesses at the two places. What is true of level is also equally true of electric potential. In other words, *we can measure the electric potential difference between two points in terms of the work done in moving a unit positive charge from one point to another.*

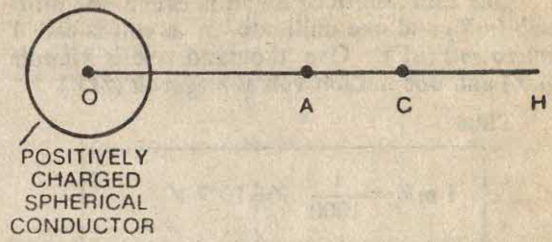


Fig. 7.13.

Let us consider a spherical conductor, charged positively (Fig. 7.13) and let *A* and *C* be two points on the line *AH*. If a unit *positive charge be placed at *C*, it will experience a force of repulsion, tending to take it away from the sphere and so in moving it to *A*, work has to be done against this force of repulsion. Hence, the potential at *A* is greater than that at *C*. Thus, as we move towards a positively charged body the potential increases and as we move further away, the potential decreases. *The work done in moving a unit positive charge from one point to the other against the electrical force measures the* **potential difference** *between the two points.*

$$\text{Potential difference } (V) = \frac{\text{Work done (W)}}{\text{Charge } (Q)}$$

$$\boxed{W = VQ}$$

Since work is measured in *joule* in *SI* system, *unit difference of potential exists between two points if one* **joule** *of work is done in moving* **one coulomb** *of charge from one point to the other against the electric force.* The unit potential difference, so defined, is called **volt** in honour of *A*. VOLTA who invented the battery. volt is denoted by the letter *V*.

$$1 \text{ volt} = \frac{1 \text{ joule}}{1 \text{ coulomb}}$$

or $$\boxed{1\ V = 1\ J/1\ C}$$

Potential at any point is measured by the work done in bringing a unit positive charge from infinity to that point, against the electric force. Thus a volt is the potential at a point when one joule of work is done in bringing one coulomb of charge from *infinity* to that point.

---

*A unit *negative* charge in an electric field would also experience the force and in response to this force, the charge would move. Thus the work would be done by the source of field.

One thousandth of a volt is called one *milli-volt* (mV) and one millionth of a volt is called *micro-volt* (μV). One thousand volt is *kilovolt* (kV) and one million volt is *megavolt* (MV).

Thus

$$\boxed{\begin{array}{l} 1\ mV=\dfrac{1}{1000}\ V=10^{-3}\ V \\ 1\mu V=10^{-6}\ V=\dfrac{1}{1000000}\ V \\ 1\ kV=10^{3}\ V \\ 1\ MV=10^{6}\ V \end{array}}$$

Thus *electron volt* (eV), a widely used unit in atomic physics, is the energy acquired by an electron that has been accelerated by a potential difference of 1 volt.

$$1\ eV=1{\cdot}6\times10^{-19}\text{ joule}$$

7.10. ELECTRIC CURRENT

We have learnt about the transfer charge, that is, when two charged conductors at different electrical potential are joined (Fig. 7.14), positive electric charge will flow from the conductor at a higher potential to the conductor at a lower potential. (*Electrons* carrying a negative charge will flow from the conductor at a lower potential to the conductor at a higher potential). **Such a flow of electric charge is called an electric current**. *Thus an electric current flows when there is an electric potential difference.*

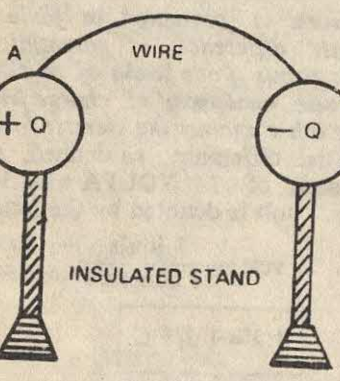


Fig. 7.14.

To keep an electric current flowing through a conductor, it is obviously necessary *to maintain the potential difference between its ends*, that is to maintain a difference in electrical energy level between the ends. This, of course, requires the expenditure of some other form of energy. Taking again the hydrostatic analogy (Fig. 7.15), if a continuous current of water is to be obtained between the two vessels, their difference of levels must be maintained by pumping back water from the vessel in which it is at a lower level to the one in which its level is higher *at the same rate* at which it flows from the latter to the former (Fig. 7.15).

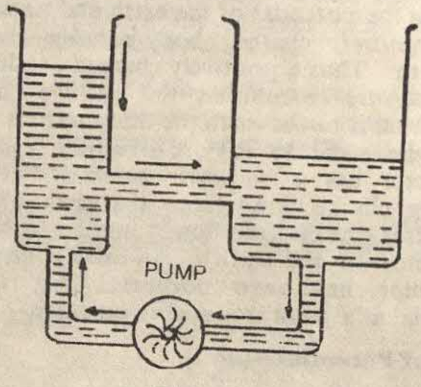
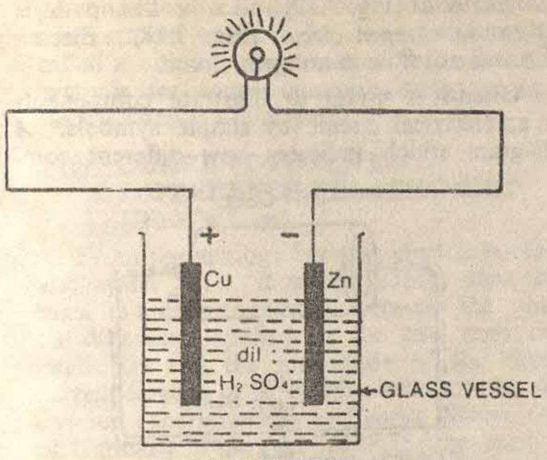


Fig. 7.15

When the pump is operating, it produces pressure differences between the various parts of the system and water flows from regions of higher pressure to regions of lower pressure.

The flow of charge round an electric circuit is similarly produced by differences in electrical pressures produced by the battery. Such a difference in electrical pressures is called the *potential difference.* In order that electric current should pass from one point in the circuit to another, the battery or any other electric source must maintain a potential difference between two points. Energy is required to keep the current moving round the circuit. The energy comes, of course, from the battery or the source of steady current. One of the earliest devices capable of providing a source of steady current was invented in 1800 by the Italian Physicist A-Volta. It is called a *voltaic cell.* Since then various kinds of dry cells and storage batteries have been devised.

A voltaic cell consists of two plates, one of *copper* and the other of *zinc*, both dipped in a vessel containing *dilute sulphuric acid* and kept apart each other as shown in (Fig. 7.16). When these plates are connected by a copper wire, *an electric current flows from copper to*



(A VOLTAIC CELL)

Fig. 7.16

zinc outside the vessel and *from zinc to copper inside it.* (Electrons move from zinc to copper outside the vessel). This shows that as zinc reacts with dilute sulphuric acid, the zinc plate gets negatively charged, while the copper gets positively charged. Thus *copper plate is at a higher potential than the zinc plate.* It will also be seen that when the plates are connected together, bubbles of hydrogen rise on the surface of the copper plate and zinc goes into solution forming zinc sulphate. *It is the energy liberated from this chemical action which maintains the current. Hence the source of electricity in this case in the chemical action between zinc and sulphuric acid.* In other words in this device, *chemical energy is changed into electrical energy.* Such a device is called a *primary cell.*

Unit of electric current

The analogy between a continuous steady flow of water along a tube and a continuous steady flow of electricity along a wire is a useful aid to understanding some of the principles concerning an electric current.

Consider a tube *AB* [Fig. 7.17 (*a*)] which has a continuous steady flow of water along it in the direction *A* to *B*. The *current* of water is the volume of water *per second* passing any section *S*, and if 25 m^3 pass *S* in 5 seconds, the current$=\frac{25}{5}=5\ m^3s^{-1}$. **The time element is therefore, concerned in the idea of current.** From the water analogy, if 15 coulombs of electricity flow past the point *T* in the wire *MN* of [Fig. 7.17 (*b*)] in 3 seconds, the electric current$=\frac{15}{3}=5$ coulombs/second. The current is the same at all points of the wire if the flow of electricity along it is a steady one. Generally, if *Q* is the quantity of charge flowing past a point in a wire in *t* sec, the current *I* is given by

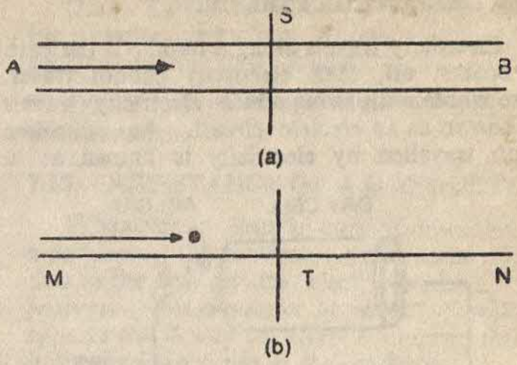


Fig. 7.17 (*b*)

$$\boxed{I=\frac{Q}{t}} \quad \text{or} \quad \boxed{Q=It}$$

Thus, the electric current is the amount of charge passing through a given point in one second. Current is a *scalar quantity.*

Where *Q* is in coulombs and *t* is in seconds, then *I* is in amperes. An ampere is the practical unit of current and is denoted by the letter *A*.

Thus 1 ampere$=\frac{1\ \text{coulomb}}{1\ \text{second}}$ and corresponds to a flow of $6{\cdot}25\times10^{18}$ electrons/second past a point.

Hence current is *one ampere* if a charge of *1 coulomb* flows through any cross-section of the conductor in *one second.*

This, however does not mean that if there is a current of 1 ampere through a wire, $6{\cdot}25\times10^{18}$ electrons are actually flowing from one end of the wire to the other every second. It only means that there is a *drift* of so many electrons every second (not necessarily involving the same electrons) from one end of the wire to the other.

Sometimes, smaller units for measuring current are used. They are ***milliampere*** (*mA*) and *microampere* (μA).

$$1mA=1/1000\ A=0{\cdot}001A$$

$$1\mu A=\frac{1}{1000000}A=0{\cdot}000001\ A$$

7.11. ELECTRIC CIRCUIT

Electricity travels along a path. If the path is broken off, then electricity cannot travel. The whole path along which electricity travels is known as an *electric circuit*. An unbroken path travelled by electricity is known as a *closed circuit* (Fig. 7.19) and a broken path is known as an *open circuit* (Fig. 7.18). Electricity will not flow in an open circuit.

Often it is useful to illustrate components in an electrical circuit by simple symbols. *A diagram which indicates how different com-*

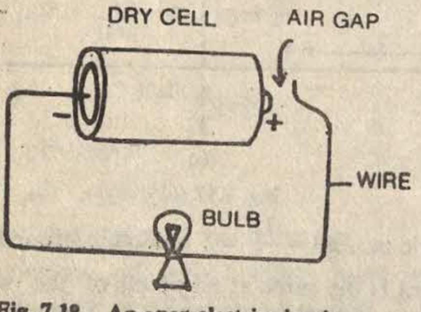


Fig. 7.18. An open electric circuit

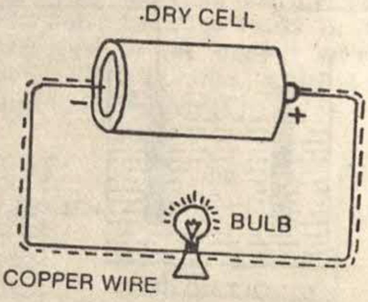
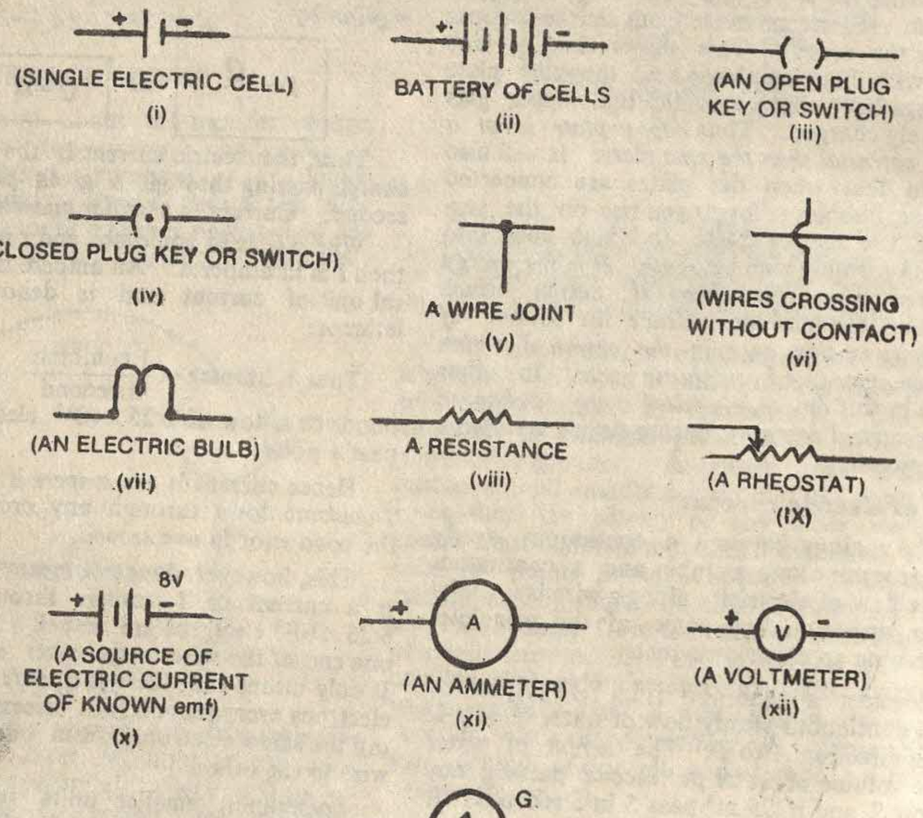


Fig. 7.19. An closed electric circuit.



(SINGLE ELECTRIC CELL) (i)

BATTERY OF CELLS (ii)

(AN OPEN PLUG KEY OR SWITCH) (iii)

(A CLOSED PLUG KEY OR SWITCH) (iv)

A WIRE JOINT (V)

(WIRES CROSSING WITHOUT CONTACT) (vi)

(AN ELECTRIC BULB) (vii)

A RESISTANCE (viii)

(A RHEOSTAT) (IX)

(A SOURCE OF ELECTRIC CURRENT OF KNOWN emf) (x)

(AN AMMETER) (xi)

(A VOLTMETER) (xii)

(A GALVANOMETER) (xiii)

Fig. 7.20

ponents in a circuit have been connected, using conventional symbols for the components, is called a **circuit diagram.** The conventional symbols for some common components of electric circuits are given in (Fig. 7.20).

7.12. CURRENT-POTENTIAL DIFFERENCE RELATIONSHIP (Ohm's Law):

From the analogy between electric potential and water level, it would appear that there must be a definite relation between the potential difference applied to the two ends of a conductor and the magnitude of the electric current flowing in it. Such a relation was discovered experimentally by *George Simon Ohm* of Germany in the year 1827 in the form of what is known as Ohm's Law. The law states:

"The ratio of the potential difference across the ends of a conductor to the current flowing through is constant so long as the physical conditions, i.e., temperature, density etc. of the conductor remain the same."

Suppose that a current of 4 amperes is flowing through an electric wire connected to the 240 volts main supply. What would the current be if the main voltage falls to 120 volts? Ohm's Law tells us that since the potential difference (voltage) has been halved, the current will be reduced in the same proportion, *i.e.*, halved. The net current is, therefore, 2 amperes. If the voltage had dropped to 80 volts (*i.e.*, 1/3 of its original value) the current would drop proportionately 4/3 amperes, (*i.e.*, 1/3 of its original value). In each case,

$$\frac{\text{Potential Difference}}{\text{Current}} \text{ is the same } i.e.$$

$$\frac{240}{4}=60\,;\ \frac{120}{2}=60 : \frac{80}{4/3}=60$$

If V=Potential difference

and I=current, then

mathematically speaking, Ohm's Law can be stated as

$$\boxed{\frac{V}{I}=\text{constant}}$$

or $\boxed{\frac{V}{I}=R}$ where R is a constant known as **resistance** of a conductor.

Ohm's Law is valid under definite conditions for metallic conductors. It fails for solutions, semi-conductors and for gases

Ohm's Law provides a basis for measuring the resistance.

7.13. RESISTANCE OF A CONDUCTOR:

Whenever an electric current flows through a conductor, the conductor offers some opposition to the flow of the electric current. *This property of the conductor by virtue of which it opposes the flow of an electric current through it is called resistance of the conductor.*

According to Ohm's Law, resistance (R) is measured by the ratio of the potential difference (V) developed at the two ends of the conductor to the current (I) passed through it.

$$\text{Resistance } (R)=\frac{\text{Potential Difference } (V)}{\text{Current } (I)}$$

Resistance is measured in **ohms.** The symbol for ohm is Ω.

If a potential difference of 1 volt is developed across the two ends of a conductor when a current of 1 ampere flows through it, then the resistance of the conductor is said to be one ohm.

Hence $\boxed{I \text{ ohm}=\frac{1 \text{ volt}}{1 \text{ ampere}}}$

The resistance of a conductor (pure metal) varies with the change in temperature. For an alloy like *manganin* (84% Cu; 4% Ni and 12% Mn) or *constantan* (60% Cu and 40% Ni), there is extremely small change in resistance with change in temperature and hence it is for this reason that they are mostly used for making standard resistances.

A conductor possessing a certain resistance is usually called a *resistor*.

7.14. EXPERIMENTAL VERIFICATION OF OHM'S LAW

Set up a circuit as shown in (Fig. 7.21).

XY=a *Eureka wire* about 100 cm long.

B=a *battery* of a number of cells which sends current round the circuit.

K=a *key* for making and breaking the circuit.

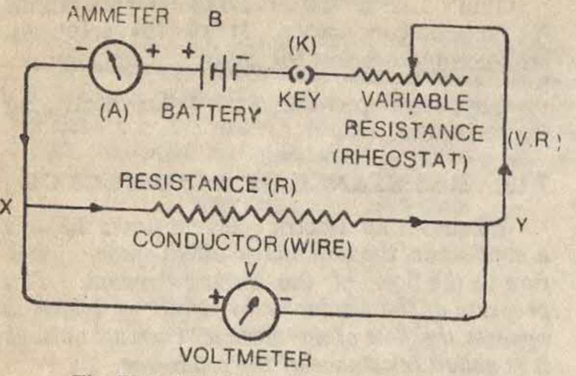


Fig. 7.21. Verification of Ohm's Law.

A=an *ammeter* which measures *I*, the strength of the current in *amperes.*

V=a *voltmeter* which measures, *V*, the potential difference between the ends of the wire in volts.

V.R.—*Variable resistance* or *Rheostat* for varying the strength of the current by changing the total resistance of the circuit.

The positive terminal of the battery should be connected to the positive terminal of voltmeter and ammeter.

Close the circuit and record the readings of the ammeter and volt-meter. Repeat the experiment six times by changing the strength of the current with the help of the variable resistance or rheostat.

It will be found that the ratio of the potential difference (*V*) and the current (*I*) *i.e.*, $\frac{V}{I}$ is constant. This constant is equal to the resistance (*R*) of the wire *XY*.

If a graph is plotted taking potential difference (*V*) along *X*-axis and current (*I*) along *Y*-axis, we get a straight ling as shown in (Fig. 7.22) ; this means

$$V \propto I$$

It also verifies Ohm's law.

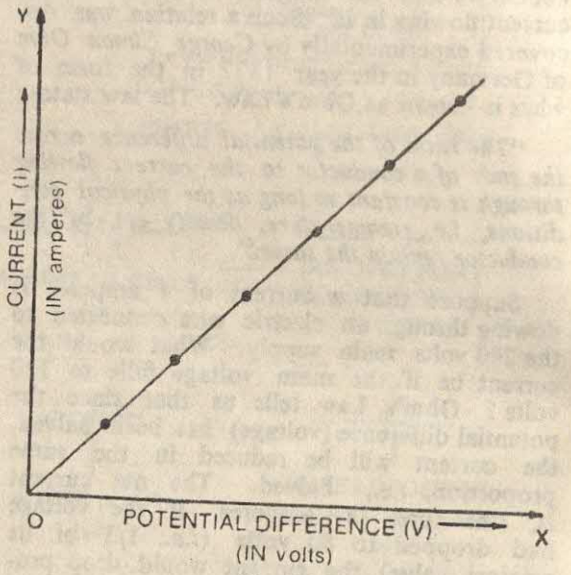


Fig. 7.22.

S.No.	*Potential Difference V (in volts)*		*Current I (in amperes)*		$\frac{V}{I}=R$ *(in ohms)*
	Observed	*Corrected*	*Observed*	*Corrected*	
1.					
2.					
3.					
4.					
5.					
6.					

Here it should be borne in mind that the current should not be passed for a long time otherwise heat is produced in the wire and that introduces an error in the result. Also the sliding contact of the variable resistance (V.R.) should be moved so as to increase the current by equal steps as far as possible.

7.14. COMBINATION OF RESISTANCES :

There are two distinct ways in which the resistances can be connected :

(*i*) Resistances in series ; and

(*ii*) Resistances in Parallel.

Resistances in Series : In many applications of electrical circuits two or more resistances (or conductors) are often connected end to end, so that the current must flow first through one and then through the other. Such a connection is called a *series* connection. It is an important property of a series connection that the *same strength of current* flows through all parts of it.

The current does not get gradually used up as it flows around the circuit. In this respect, it is similar to the flow of water through a long pipe which has no side branches. The same volume of water per second must flow, at a given instant, through every cross-section of the pipe. If this were not so, then either the amount of water in the pipe would increase and burst, the pipe or the amount of water in the pipe would decrease until the pipe was nearly empty.

Let R_1 R_2, R_3 be the resistances of the various conductors joined in series (Fig. 7.23) and I be the current flowing in them. If V_1, V_2 and V_3 be the potential differences developed across the ends of these conductors, the total potential difference (V) across the combination is given by

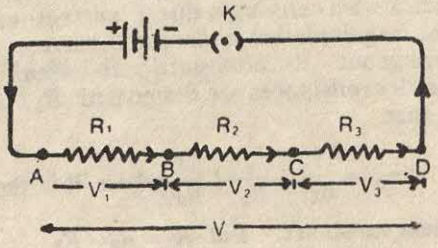


Fig. 7.23.

$$V=V_1+V_2+V_3 \qquad ...(1)$$

Now, by Ohm's law, we have

$V=IR$, where R=total resistance of the combination

$\therefore \quad V_1=IR_1$

$V_2=IR_2$

and $V_3=IR_3$ because the same current is flowing through all the conductors.

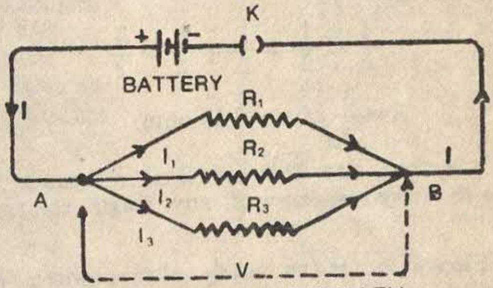
Substituting these values in the equation (1), we have

$$IR=IR_1+IR_2+IR_3$$

or
$$\boxed{R=R_1+R_2+R_3} \qquad ...(2)$$

Thus the total resistance of the circuit is equal to the sum of the resistances of the individual conductors joined in series. The total resistance increases by such a combination of conductors.

(*ii*) *Resistances in Parallel.* When two or more resistances conductors are connected between two points so that the current *divides* between them and then rejoins, they are said *to be in parallel.* The circuit diagram for such a combination of resistances is shown in Fig. (7.24).



(RESISTANCES IN PARALLEL)

Fig. 7.24.

Let R_1, R_2 and R_3 be the resistances of the conductors joined in parallel so that the total current (I) of the circuit is divided into three parts I_1, I_2, and I_3 flowing through the conductors respectively. Here, the two ends of all the conductors are joined together at A and B. Therefore, the potential difference at the ends of each conductor is the same (say V).

Now the total current flowing in the combination is given by

$$I=I_1+I_2+I_3 \qquad ...(1)$$

Applying Ohm's law, we have

$$I=\frac{V}{R} \text{ where } R=\text{total resistance}$$

of the combination.

$$I_1=\frac{V}{R_1}$$

$$I_2=\frac{V}{R_2}$$

and $$I_3=\frac{V}{R_3}$$

The equation (1) reduces to

$$\frac{V}{R}=\frac{V}{R_1}+\frac{V}{R_2}+\frac{V}{R_3}$$

or $$\boxed{\frac{1}{R}=\frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3}} \quad ..(2)$$

Thus when a number of resistances are connected in parallel, the reciprocal of the combined resistance is equal to the sum of the reciprocals of the individual resistances.

Suppose we have three resistances 2 ohm each put in parallel, then the combined resistance R is given by

$$\frac{1}{R}=\frac{1}{2}+\frac{1}{2}+\frac{1}{2}=\frac{3}{2}$$

$$R=\frac{2}{3}\text{ ohm}=0{\cdot}66\text{ ohm}$$

It is, thus, clear that the total resistance is **less** than the resistance of any single conductor.

Electric lamps are nearly always wired in parallel. Lamps wired in parallel have a smaller total effective resistance than the same number of lamps wired in series. Parallel connection of electric resistances is widely used in industry and household purposes.

7.15 FACTORS AFFECTING RESISTANCE (SPECIFIC RESISTANCE OR RESISTIVITY) :

The various factors that affect the resistance of a conductor are :—

(1) Temperature :

The resistance of all substances changes to some degree with changes in temperature. In the case of pure metals and most metallic alloys, *the resistance increases with a rise in temperature.* Carbon, semiconductors, and many electrolytic solutions, on the other hand, show a *decrease in resistance* as their temperature is raised. A few special alloys, such as constantan and manganin, show *very slight changes in resistance* over a considerable range of temperatures. For practical purposes, the resistance of these alloys can be considered independent of temperature.

(2) Length :

Resistances in series are added to give the total resistance of the series circuit. From this fact we can conclude that 10 meters of a certain conductor should have a resistance 10 times that of 1 meter of the same conductor. Experiments prove this relationship to be true ; *the resistance of a uniform conductor is directly proportional to the length of the conductor*

$$\boxed{R \propto l}$$

where R is the resistance of the conductor and l is the length of the conductor.

(3) Area of cross-section :

If three *equal* resistances are connected in an electric circuit, the equivalent resistance is one-third the resistance of any one branch. The equal currents in the three branches add to give the total current in the circuit.

Assuming the three resistances to be three similar wires 1 meter in length, each having a cross-sectional area of 0·1 cm^2, we can think of the equivalent resistance as a similar wire of the same length but having a cross-sectional area of 0·3 cm^2. This deduction is reasonable, since a wire carrying a direct current of constant magnitude has a constant current density throughout its cross-sectional area. If the parallel resistances are designated R_1, R_2 and R_3 then

$$\frac{1}{R}=\frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3} \text{ where } R \text{ is the equivalent resistance.}$$

valent resistance. But $R_1=R_2=R_3$

So $$\frac{1}{R}=\frac{3}{R_1}$$

and $$R_1=3R$$

We can conclude that the resistance of the large wire, R, is one-third the resistance of the small wire, R_1, and experiments prove this conclusion to be true. *The resistance of a uniform conductor is inversely proportional to its cross-sectional area.*

$$\boxed{R \propto \frac{1}{A}}$$

where A is the cross-sectional area of the conductor. In case of a wire, $A = \pi r^2$ where r is the radius of the wire.

(4) Nature of the Materials :

A copper wire having the same length and cross-sectional area as an iron wire offers about one-sixth the resistance to the flow of electricity. A similar silver wire presents even less resistance.

Thus the resistance of a given conductor depends on the material of which it is made.

Taking these four factors into account, several useful conclusions become apparent. For a uniform conductor of a given material and temperature, the resistance is directly proportional to the length and inversely proportional to the cross-sectional area *i.e.*

$$R \propto \frac{l}{A}$$

or $$\boxed{R = \rho \frac{l}{A}}$$

where ρ is a constant of proportionality and its value depends upon the material of the wire and its temperature. This constant ρ is called the **specific resistance** or **resistivity** of the material of the wire.

From the above equation.

$$\boxed{\rho = \frac{RA}{l}}$$

We find that if,

$l = 1$ m

$A = 1$ m^2

than $\boxed{\rho = R}$

Thus, the specific resistance (or resistivity) of the material of a wire is the resistance of a wire of length 1 m and having a uniform cross-sectional area of 1 m^2 or it is the resistance offered by a cube of the material of side 1 m when current flows perpendicular to opposite faces.

Unit of specific resistance :

$$\text{Since } \rho = \frac{RA}{l}$$

$$\therefore \text{ Unit of } \rho = \frac{\text{Unit of resistance } (R) \times \text{Unit of cross-sectional area } (A)}{\text{Unit of length } (l)}$$

$$= \frac{\text{ohm} \times (\text{meter})^2}{(\text{meter})} = \textbf{ohm-meter}$$

Hence specific resistance ρ is measured in **ohm-meter** or **Ωm**

The resistivities of various materials are listed in the Table below. Note that the value of ρ is independent of the length and the area of cross-section of the wire. It depends only on the material of the wire. Thus, the specific resistance is a characteristic of the material. If the specific resistance of a material is known, the resistance of any other wire composed of the same material can be calculated.

Resistivity or Specific Resistance of some substances at 20°C

Substance	*Specific Resistance (Ohm-m)*
Aluminium	$2{\cdot}63 \times 10^{-8}$
Carbon	3500×10^{-8}
Copper	$1{\cdot}62 \times 10^{-8}$
Constantan	49×10^{-8}
Germanium	2×10^{8}
Gold	$2{\cdot}04 \times 10^{-8}$
Iron	$9 - 13 - 10^{-8}$
Lead	$20{\cdot}4 \times 10^{-8}$
Mercury	94×10^{-8}
Nichrome	100×10^{-8}
Phosphorus	1×10^{12}
Platinum	$11{\cdot}1 \times 10^{-8}$
Silver	$1{\cdot}60 \times 10^{-8}$
Sulphur	1×10^{17}
Tungsten	$5{\cdot}0 \times 10^{-8}$
Diamond	$10^{2} - 10^{3}$
Ebonite	$10^{15} - 10^{17}$
Glass (Pyrex)	10^{14}
Mica	$10^{13} - 10^{17}$
Paper (dry)	10^{12}
Water (distilled)	$10^{4} - 10^{7}$
Silicon	$10^{3} - 10^{6}$

The resistivity of most metallic conductors increases with temperature. In the case of insulators such as ebonite, glass, diamond, etc ; resistivity is very high and does not change with temperature. In between the metallic conductors and insulators, we have semiconductors, whose resistivities decrease with increasing temperature. Semiconductors are proving to be of great practical importance because of their marked change in conducting properties with temperature, impurity, concentration etc.

7-16. HEATING EFFECT OF ELECTRIC CURRENT

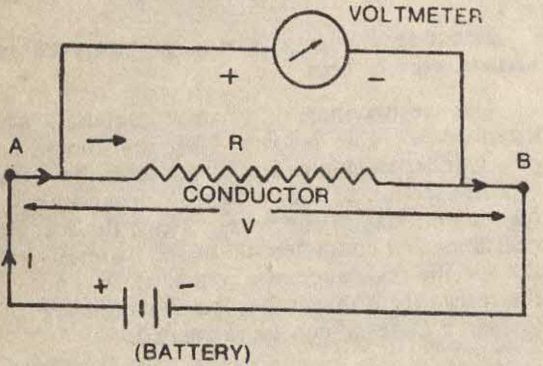


Fig. 7.25

Consider Fig. (7.25), in which a current (I) of electricity flows from *A* to *B* when the conductor (or the resistance wire) is connected to the terminals of a battery. The electric potential at *A* is greater than that at *B*. Since electricity in the wire is due to the steady drift of electrons, so the electrons moving under the influence of a potential difference between the ends of the conductor, must possess energy and this is called **electrical energy**. The fact that a conductor offers resistance to the flow of current implies that work must be done continuously to maintain a current. The role of resistance in electrical circuits is analogous to that of friction in mechanics. We know that if work is done when an electric charge is moved from one point to another in an electrical circuit, then a potential difference exists between the two points.

The amount of work done is a measure of a potential difference. The greater the work done, the bigger is the potential difference.

The unit of the potential difference is the *volt* which is defined as follows :

The potential difference between two points *A* and *B* is one volt if *one joule* of energy is released when a charge of *one coulomb* moves from point *A* to the other point *B*.

If the potential difference between two ends of the conductor *A* and *B* were 2 volts, then 2 joules of energy would be released when one coulomb of charge is moved from point *A* to the other point *B*. So, if the potential difference between the two points *A* and *B* as shown by the Voltmeter is 'V' volts, the electrical energy liberated when a charge of one coulomb moves from point *A* to point *B* will be *V joules*.

Similarly, if *three coulombs* charge is moved between the two points *A* and *B* of the conductor whose potential difference is *one volt*, then the energy released would amount to *three joules*. So, when '*Q*' coulombs of charge flow between the same potential difference (*i.e.* 1 volt), energy released will be *Q joules*.

Hence, we may conclude that the energy liberated (as heat or otherwise) when *Q* coulombs of electricity move between two points having potential difference '*V*' is given by—

$$\boxed{W\,(\textit{joules}) = Q(\textit{coulombs}) \times V(\textit{volts})}$$

or Work done by the electric current
=Amount of electric charge moved
×Potential difference between two points

Recollecting the relation between charge and electric current, we know that the electric current is the quantity of charge flowing through the conductor per unit time.

The unit of current is called the *ampere and is equivalent to flow of one coulomb of electricity per second through a conductor.*

Thus, if a current of I amperes flows in a conductor for *t* seconds, the total quantity of electricity which passes along it is given by :

$$Q\,(\textit{coulomb}) = I\,(\textit{amperes}) \times t\,(\textit{seconds})$$

Hence the *work done by the current* (or *the energy released*) is equal to

$$W\,(\text{joules}) = Q\,(\text{coulombs}) \times V\,(\text{volts})$$
$$= I\,(\text{amperes}) \times t\,(\text{seconds}) \times V\,(\text{volts})$$

or $\boxed{W = \text{V.I.}t \text{ joules}}$

or $\boxed{W = I^2Rt}$

as $V = IR$ by ohm's law

The above formulas are used in practice to calculate electrical energy or work done by an electric current. All the quantities in the formulas are easily measured.

This shows that the energy dissipated is the product of the square of the current, the resistance R and time t. This energy appears mostly as heat, but sometimes also as light. In the case of heaters, electric irons, radiators; toasters, etc; electrical energy is mostly converted into heat. In the case of electric lamps about 5% only of the electrical energy is converted into visible light.

Let us suppose that all the electrical energy dissipated in the conductor appears as heat. Then, since, one calorie of heat is equivalent to 4.18 joule, the amount of heat (H) generated can be obtained by using equation

$$W=I^2Rt=VIt$$

and is given by

$$H=I^2Rt=VIt \text{ joule}$$

$$\text{or} \quad H=\frac{I^2Rt}{4{\cdot}18} \text{ cal}$$

$$=\frac{VIt}{4{\cdot}18} \text{ cal}$$

7.17. ELECTRICAL POWER

Power is defined as the amount of work done per unit time. It involves the time, t, in which a particular amount of work is done or energy is liberated.

Thus $P=$ Work done (or energy liberated) per second

$$=\frac{W}{t}$$

In mechanics, the unit of power is *joule/second*

Thus, in electricity, the electrical power

$$P=\frac{W}{t}=\frac{QV}{t} \text{ joules/second}$$

$$=\frac{IV\,.\,t}{t}=\text{I.V. joules/second}$$

A rate of working equal to one joule/second is called a **watt**, the unit of electrical power.

We, therefore, obtain the important expression

$$\boxed{P=\text{I.V. watts}} \qquad \ldots(ii)$$

Since $I=\frac{V}{R}$ by Ohm's Law for the conductor, the power is also given by

$$P=I\times(I\times R)=I^2.R \text{ watts} \qquad \ldots(iii)$$

$$\text{and also} \quad P=\frac{V}{R}\times V=\frac{V^2}{R} \text{ watts} \qquad \ldots(iv)$$

Watt is very small unit of electrical power. So in practice we use bigger unit of power. A large unit of power in common use is the *Kilowatt*.

1 Kilowatt (kW) = 1000 watt (W)

7.18. WORK DONE BY A CURRENT IN TERMS OF POWER AND TIME (ELECTRIC ENERGY)

You know that power P is given as

$$P=\frac{W}{t}$$

$$\text{So,} \quad W=P\times t \qquad \ldots(v)$$

From equation (v), you can calculate the work done by electric current in terms of power and time.

$$\text{Thus} \quad \boxed{W(joules)=P(watts)\times(seconds)}$$

The joule or **watt second** is too small a unit for conveniently measuring large quantities of electrical energy. The *unit* of energy commonly used is the **kilowatt-hour (kWH)**. The domestic electricity meter measures the amount of electrical energy consumed in the home in terms of this unit.

The kilowatt-hour is the amount of energy consumed in one hour, when the power or rate of doing work is one kilowatt.

$$\therefore \quad 1 \text{ kilowatt-hour} = 1000 \text{ watt for 1 hour}$$

$$= 1000 \text{ watt for 3600 seconds}$$

$$= 1000 \text{ joule/second for 3600 seconds}$$

$$= 3600000 \text{ joule} = 3{\cdot}6\times10^6 \text{ J}$$

If the rate consumption of energy in kilowatts is given, the number of kilowatt-hours used in a certain time is given by

Number of kilowatt-hours

$$= \text{No. of kilowatt} \times \text{No. of hours}$$

$$= \frac{\text{No. of watts}}{1000}\times\text{No. of hours}$$

$$= \frac{\text{Volts}\times\text{amperes}\times\text{hours}}{1000}$$

The students should carefully note that *watt or kilowatt* is the unit of *power* and **kilowatt-hour** or **watt-hour** is the unit of the *electrical energy*.

7.19. CHEMICAL EFFECT OF CURRENT

If two small strips of platinum are connected to the terminals of a battery and dipped into a beaker of distilled water, it is difficult to pass current between them. But if a few drops of sulphuric acid are added, current begins to pass and gas bubbles appear at both plates. These bubbles are found to be that of hydrogen (H) and oxygen (O), the two constituents of water. Similarly, if two plates of copper are connected to the terminals of a battery and then dipped into copper sulphate solution, current begins to flow. One plate loses copper and the other gains an equal amount.

Faraday made a thorough study of this process of chemical action by electricity. This chemical action is called *electrolysis.* The liquid conducting electricity is called *electrolyte* The two plates such as those of platinum, copper, etc ; are called *electrodes* ; the one where the current enters is called the *anode* and the one where it leaves, the *cathode.* The vessel in which the electrolyte is contained for electrolysis is called an electrolytic cell or a *voltameter*. The majority of electrolytes are liquids, and the most important ones are aqueous solutions of acids, bases and salts.

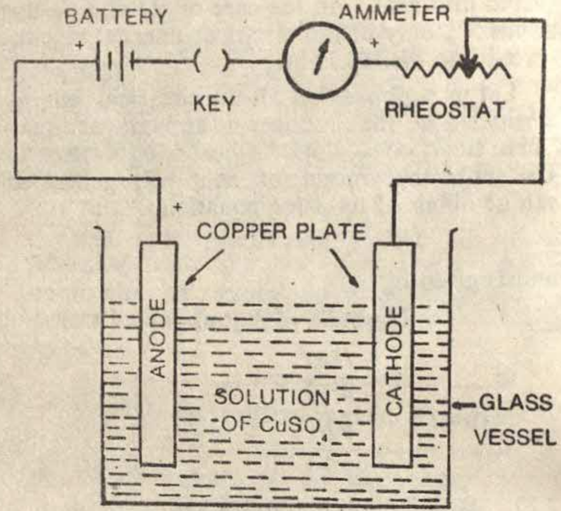
The carriers of current through the electrolyte are called *ions.* The term "ion" is applied to a charged atom or molecule moving in a liquid or gas. The ion carrying a positive charge is called positive ion or *cation* and the ion carrying a negative charge is called a negative ion or *anion.*

When a potential difference is applied between the two plates placed in a voltameter, an electric field is set up between them. The positive ions move towards the negative electrode or cathode and the negative ions towards the positive electrode or anode. The ions on reaching the electrodes give their charge to the electrodes and become neutral. These then come out as gases or deposit as a thin layer on the electrodes.

This flow of positive ions in one direction and negative ions in the opposite direction is equivalent to a current flowing in the electrolyte. The direction of this current is the same as that of the positive ions.

Copper Voltameter

A copper voltameter consists of a glass vessel containing copper sulphate solution as electrolyte and two copper plates as electrodes (Fig. 7.26). When copper sulphate is dissolved in water, it splits up into Cu^{++} and SO_4^{--} ions. The copper ions carry two units of positive charge and the sulphate ions two units of negative charge.



(COPPER VOLTAMETER)
Fig. 7.26.

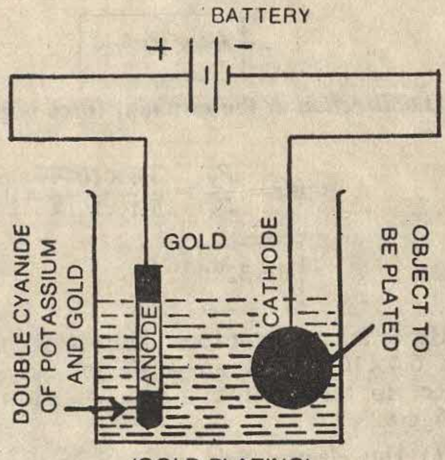
$$CuSO_4 \longrightarrow Cu^{++} + SO_4^{--}$$

When the electrodes are connected to a battery through an ammeter and a rheostat, the Cu^{++} ions move towards the negative plate cathode and after delivering their charge become neutral atoms and a reddish copper coating will be found on the cathode. The SO_4^{--} ions go to the positive plate (anode) and combine with copper atoms of the electrode to form $CuSO_4$. The $CuSO_4$ so formed goes into solution and the concentration of the solution is maintained. Thus the cathode gains as much copper as the anode loses.

Electro-plating. *It is a process of depositing electrically a coating of any desired metal on another metal object for the purpose of protecting the object from oxidation or to give it the appearance of being wholly composed of the superior metal.*

When we require a substance to be coated with a particular metal, the substance is made the cathode and the electrolyte is a solution of a salt of the metal. Thus, if we want a substance to be silver-plated, then a solution of potassium silver cyanide is taken as the electrolyte, the substance, as the cathode and a small sheet of silver as the anode. Similarly, if a substance is to be gold-plated, a solution of double cyanide of potassium and gold is taken and the anode is made of gold, to make up the loss of gold at the cathode. Fig. (7.27) illustrates how gold plating is done.

Purification of metal. Let us consider the purification of copper. Here a solution of copper sulphate is taken as the electrolyte and a plate of copper is made the cathode. The copper to be purified is made the anode, so that, when the current is passed through the solution, copper is deposited on the cathode. All the copper from the impure lump, forming the anode, is thus transferred to the copper plate of the cathode and the impurities fall down to the bottom. This method is commonly used in the *purification* of metals.



(GOLD PLATING)

Fig. 7.27.

SOLVED EXAMPLES

Example 1.

A comb drawn through a person's hair on a dry day causes 10^{12} electrons to leave the person's hair and stick to the comb.

(*a*) Is the force between the comb and the hair attractive or repulsive ?

(*b*) What is the magnitude of this force when the comb is 1·0 m from the person's hair ? Electronic charge $= -1{\cdot}60\times10^{-19}$ C.

Solution.

(*a*) The force is *attractive* because the charge on the comb is negative and that on the hair is positive. Unlike charges attract.

(*b*) From Coulomb's law, we have

$$F=K\,\frac{q_1q_2}{r^2}\ \text{ where } K=9{\cdot}0\times10^9\ Nm^2/C^2$$

$$=\frac{(9{\cdot}0\times10^9)(10^{12})(+1{\cdot}6\times10^{-19})\times(10^{12})(-1{\cdot}6\times10^{-19})}{(1{\cdot}0)^2}$$

$=-2{\cdot}3\times10^{-4}\ N$; the minus sign means that the force is attractive.

Example 2.

(*a*) The force required to give a 1000 kg car an acceleration of 2·5 m/s² is $2{\cdot}50\times10^3$ N. What would the charge have to be on two small spheres 1·0 m apart to produce the same force between the spheres, if we assume that both spheres have the same charge ?

(*b*) If the charge on each sphere is negative, how many excess electrons are there on each sphere ? Electronic charge $=1{\cdot}60\times10^{-19}$ C.

Solution.

(*a*) From Coulomb's law, with $q_1=q_2=q$ (say), we have

$$F=K\,\frac{q_1q_2}{r^2}=K\,\frac{q^2}{r^2}$$

where $K=9{\cdot}0\times10^9\ \text{Nm}^2/\text{C}^2$.

Hence $$q^2=\frac{Fr^2}{K}$$

$$=\frac{(2{\cdot}50\times10^3)(1{\cdot}0)^2}{9{\cdot}0\times10^9}=2{\cdot}77\times10^{-7}\ \text{C}^2$$

and so $q=5{\cdot}26\times10^{-4}\ \text{C}=526\ \mu\text{C}$

Two charges of 526 μC at a distance of 1 m apart would, therefore, produce this relatively large force of $2{\cdot}5\times10^3$ N.

(*b*) The charge on the electron is $1{\cdot}60\times10^{-19}$ C. Hence the number *n* of electrons in 526 μC is

$$n=\frac{526\ \mu\text{C}}{1{\cdot}60\times10^{-19}\ \text{C/electron}}$$

$$=\frac{526\times10^{-6}\ \text{C}}{1{\cdot}60\times10^{-19}\ \text{C/electron}}$$

$$=\boxed{3{\cdot}29\times10^{15}\ \text{electrons}}$$

Example 3.

(*a*) Three charges are arranged at the corners of a right triangle, as shown in Fig. (7.28), where q_B and q_C are located on the X-axis. Find the magnitude and direction of the resultant force acting on q_C, if the charges are $q_A=-6\ \mu C$, $q_B=+4{\cdot}0\ \mu C$ and $q_C=+2{\cdot}0\ \mu C$.

(*b*) What is the electric field strength at the position occupied by the charge q_C?

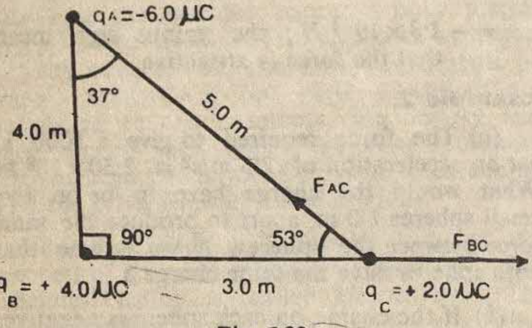


Fig. 7.28.

Solution.

(*a*) The force exerted on q_C by q_A is

$$F_{AC}=\frac{Kq_Aq_C}{r^2}$$

$$=\frac{(9{\cdot}0\times10^9)(-6{\cdot}0\times10^{-6})(+2{\cdot}0\times10^{-6})}{(5{\cdot}0)^2}$$

$$=-4{\cdot}3\times10^{-3}\ \text{N}$$

This is an *attractive* force (the sign is $-$) and is directed from q_C toward q_A along the line joining q_A and q_C. Also

$$F_{BC}=\frac{(9{\cdot}0\times10^9)(+4{\cdot}0\times10^{-6})(+2{\cdot}0\times10^{-6})}{(3{\cdot}0)^2}$$

$$=+8{\cdot}0\times10^{-3}\ \text{N}$$

This is a *repulsive* force directed along the positive *X*-axis and away from q_B at q_C.

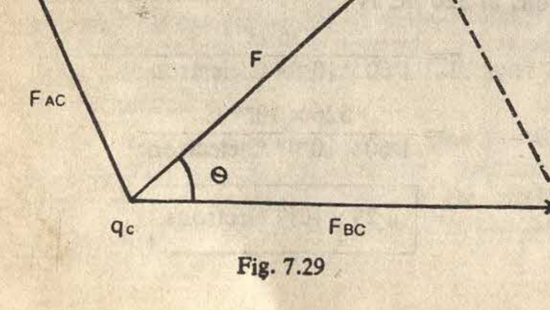


Fig. 7.29

The two forces on q_C are as shown in Fig. (7.29). To find the resultant we first find the *X* and *Y* components of the two force vectors at *C*. The angles in the triangle can be found from our knowledge of the three sides of the triangle.

$$F_X=8{\cdot}0\times10^{-3}\ \text{N}-(4{\cdot}3\times10^{-3}\ \text{N})\cos 53^\circ$$

$$=(8{\cdot}0-2{\cdot}6)\times10^{-3}\ \text{N}=5{\cdot}4\times10^{-3}\ \text{N}$$

$$F_Y=(4{\cdot}3\times10^{-3}\ \text{N})\sin 53^\circ$$

$$=3{\cdot}4\times10^{-3}\ \text{N}$$

Then, we have

$$\textbf{Resultant force}=F=\sqrt{F_X^2+F_Y^2}$$

$$=\sqrt{(5{\cdot}4)^2+(3{\cdot}4)^2}\times10^{-3}\ \text{N}$$

$$=\boxed{6{\cdot}4\times10^{-3}\ \text{N}}$$

The *direction* of the resultant force is given by

$$\tan\theta=\frac{F_Y}{F_X}=\frac{3{\cdot}4\times10^{-3}}{5{\cdot}4\times10^{-3}}=0{\cdot}63$$

and so $\boxed{\theta=32^\circ}$

Hence the resultant force on q_C is of magnitude $6{\cdot}4\times10^{-3}$ N at an angle of 32° with respect to the positive *X*-axis, as shown in the figure.

(*b*) The electric field at q_C is in the *same direction* as the resultant force on q_C found in (*a*). Hence the magnitude of the electric field is

$$E=\frac{F}{q_C}=\frac{6{\cdot}4\times10^{-3}\ \text{N}}{2{\cdot}0\times10^{-6}\ \text{C}}$$

or $E=\boxed{3{\cdot}2\times10^3\ \text{N/C}}$

Example 4

A 12-V storage battery drives 50 C of charge through a light bulb in 1 minute.

(*a*) How much work has been done by the battery?

(*b*) What is the electric power?

Solution

(*a*) Since the voltage, or potential difference, is the *work done per unit charge*, or

$$V_{AB}=\frac{W}{q}$$

We have, $W = qV_{AB}$

$$= (50\ \mathrm{C})(12\ \mathrm{V})$$

$$= \boxed{600\ \mathrm{J}}$$

(*b*) Since power is the rate at which work is done,

$$P = \frac{W}{t}$$

and so $P = \frac{600\ \mathrm{J}}{60\ \mathrm{s}}$

$$= 10\ \mathrm{J/s}$$

$$= \boxed{10\ \mathrm{W}}$$

Hence, the power delivered by the storage battery is the same as that consumed by a 10-W light bulb.

Example 5

An electron in a TV set is accelerated toward the screen by a voltage of 1000 V. The screen is 35 mm from the electron source.

(*a*) How much work is done by the voltage in accelerating the electron ?

(*b*) What is the speed of the electron when it strikes the screen ?

Electronic charge $= 1{\cdot}6 \times 10^{-19}$ C ; mass of the electron $= 9{\cdot}1 \times 10^{-31}$ kg.

Solution

(*a*) Since the work done per unit charge by the field is

$$\frac{W}{q} = V,$$

we have $W = qV$

$$= (1{\cdot}6 \times 10^{-19})(1000)\ \mathrm{J}$$

$$= \boxed{1{\cdot}6 \times 10^{-16}\ \mathrm{J}}$$

(*b*) By the principle of conservation of energy all this work must be converted into kinetic energy of the electron, hence

$$\text{K.E.} = \frac{1}{2} mv^2 = 1{\cdot}6 \times 10^{-16}\ \mathrm{J}$$

and so $v = \left[\frac{2(1{\cdot}6 \times 10^{-16})\ \mathrm{J}}{9{\cdot}1 \times 10^{-31}\ \mathrm{kg}}\right]^{\frac{1}{2}}$

$$= \boxed{1{\cdot}9 \times 10^{7}\ \mathrm{ms^{-1}}}$$

Note that the distance between source and screen is of no importance here. The crucial factor is the voltage between source and screen.

Example 6

Consider two point charges, $q_1 = +1{\cdot}0\ \mu C$ and $q_2 = +2{\cdot}0\ \mu C$ separated by a distance of 10 m, as in Fig. 7.30.

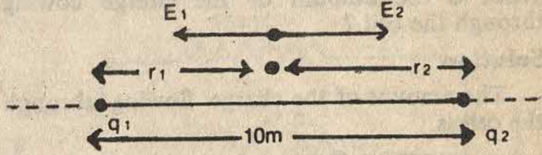


Fig. 7.30

At what point on the line (or on its extension) joining the charges is the electric field zero ?

Solution

Since the electric field strength is a *vector* and the two charges are positive, the only place where the fields due to the two charges can cancel is on the line between the two charges, for only here are the two electric field vectors in opposite directions.

Let r_1 be the distance from q_1 to the point where the field vanishes, and let $r_2 = (10 - r_1)$ be the distance from q_2 to the same point. Then, we have, from the definition of the electric field,

$$E_1 = \frac{Kq_1}{r_1^2}$$

$$E_2 = \frac{Kq_2}{r_2^2} = \frac{Kq_2}{(10 - r_1)^2}$$

At the point where field vanishes, $E_1 = E_2$ in magnitude, and they are in the opposite direction Hence, we have

$$\frac{K(1{\cdot}0\ \mu\mathrm{C})}{r_1^2} = \frac{K(2{\cdot}0\ \mu\mathrm{C})}{(10 - r_1)^2}$$

or $(10 - r_1)^2 = 2r_1^2$

or $10 - r = \sqrt{2}\, r_1$, from which

$$2{\cdot}41\ r = 10\ \mathrm{m}$$

or $r_1 = \boxed{4{\cdot}1\ \text{m from charge } q_1}$

Hence the point where the electric field vanishes is on the line between the two charges, and 4·1 m from the smaller charge. There is no other point on the line joining the two charges where the field vanishes, since outside the charges the two fields are in the same direction. Of course, as $r \to \infty$, $\vec{E} \to 0$.

Example 7

A current of 15A is maintained for 30 min through an electrolytic cell containing $CuSO_4$. What is the amount of the charge flowing through the cell ?

Solution

The amount of the charge flowing through the cell is

$$Q = It$$
$$= 15 \times 30 \times 60 \text{ C}$$

as $I = 15$ A and $t = 30 \times 60$ seconds

$$\therefore \quad Q = \boxed{2{\cdot}7 \times 10^4 \text{ C}}$$

Example 8

The resistance of a graphite rod is $3{\cdot}0 \times 10^{-1}\ \Omega$.

(*a*) What voltage must be applied across the two ends of the rod to produce a current of 10A through the rod ?

(*b*) If the required voltage is supplied by a battery which delivers current for 10 min, how much work does the battery do ?

Solution

(*a*) From Ohm's law,

$$V = IR$$
$$= 10 \times 3{\cdot}0 \times 10^{-1} \text{ volt}$$
$$= \boxed{3 \text{ V}}$$

(*b*) Since, work done $= W = QV = 3Q$, and $Q = It = 10 \times 10 \times 60$ C $= 6 \times 10^3$ C

We have $\quad W = 3 \times 6 \times 10^3$ J

$$= \boxed{1{\cdot}8 \times 10^4 \text{ J}}$$

Example 9

What is resistance at 0°C of a 1·0 m long piece of no. 5 gauge copper wire which has a cross-sectional area of 16·8 mm² ? The resistivity if copper is $1{\cdot}7 \times 10^{-8}\ \Omega$. m.

Solution

Here, $\quad l = 1{\cdot}0$ m

$$A = 16{\cdot}8 \text{ mm}^2 = 16{\cdot}8 \times 10^{-6} \text{ m}^2$$
$$\rho = 1{\cdot}7 \times 10^{-8} \text{ ohm. m}$$

using the basic equation

$$R = \frac{\rho\, l}{A}, \text{ we have}$$
$$R = \frac{(1{\cdot}7 \times 10^{-8})(1{\cdot}0)}{(16{\cdot}8 \times 10^{-6})}\ \Omega$$
$$= \boxed{1{\cdot}02 \times 10^{-3}\ \Omega}$$

Example 10

Find the current delivered by a 6-*V* battery when it is connected to two light bulbs, each of resistance 50 Ω and connected :

(*a*) in parallel ; (*b*) in series.

Solution

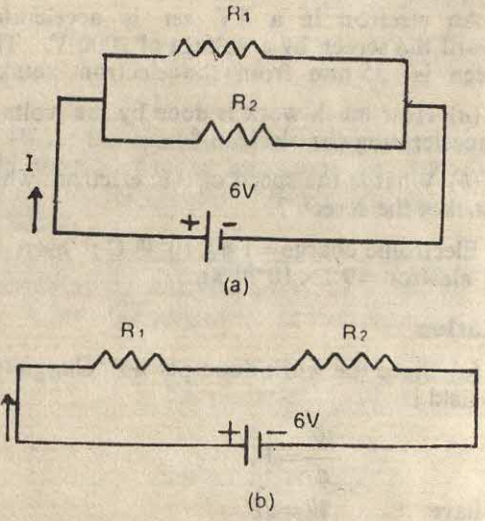


Fig. 7.31.

(*a*) The circuit is as shown in Fig [7.31(*a*)] with $R_1 = R_2 = 50\ \Omega$. Since the two resistors are in parallel, we have

$$\frac{1}{R} = \frac{1}{50} + \frac{1}{50} = \frac{2}{50}$$

or $\quad R = 25\Omega$

Hence

$$I = \frac{V}{R} = \frac{6}{25} = \boxed{0{\cdot}24\ A}$$

(*b*) In this case, the circuit is as in Fig. [7.31 (*b*)] and

$$R=R_1+R_2$$
$$=50+50=100\ \Omega$$

Then

$$I=\frac{V}{R}=\frac{6}{100}=\boxed{0{\cdot}060\ A}$$

Example 11

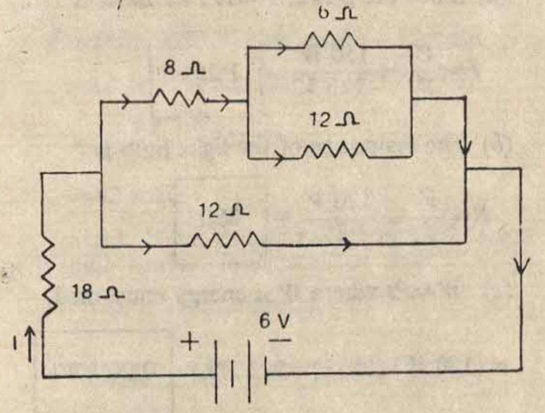


Fig. 7.32.

(*a*) In the circuit of (Fig 7·32), find the current *I* in the 18Ω resistor. The terminal voltage of the battery is 6·0 *V*.

(*b*) Find the currents flowing in the individual branches of the circuit.

Solution

(*a*) Here we must find the equivalent resistance of the circuit. In such complicated circuits the best approach in applying the laws for combining resistances in series and in parallel is to start with the innermost combination of resistances. This is the combination of the 6Ω and the 12Ω resistors in parallel. We find

$$\frac{1}{R}=\frac{1}{6}+\frac{1}{12}=\frac{1}{4}$$

or $R=4\Omega$.

We can then add this in series with the 8Ω resistor to obtain

$$R'=8+R=8+4=12\Omega$$

Next we must combine R' with the 12Ω resistor in parallel to obtain R''. We have

$$\frac{1}{R''}=\frac{1}{R'}+\frac{1}{12}=\frac{1}{12}+\frac{1}{12}=\frac{1}{6}$$

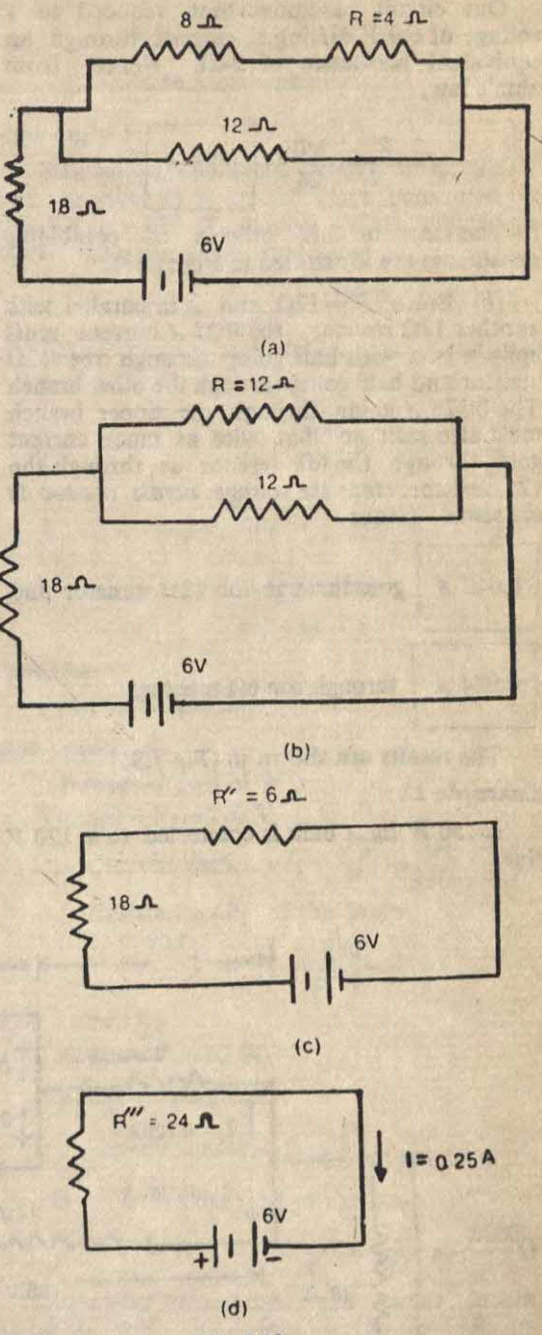


Fig. 7.33.

and so $R''=6\Omega$. This must then be combined in series with the 18Ω resistor to yield a final equivalent resistance R'''.

We have, $R'''=18+6$
$=24\Omega$.

Our circuit has now been reduced to a voltage of 6·0 *V* driving a current through an equivalent resistance of 24Ω. Hence, from ohm's law,

$$I=\frac{V}{R}=\frac{6\cdot0}{24}=\boxed{0\cdot25\ A}$$

The steps in this process of combining resistances are illustrated in Fig (7.33).

(*b*) Since $R'=12\Omega$ and is in parallel with another 12Ω resistor, the 0·25 *A* current must split in two, with half going through the 12Ω resistor and half going through the other branch The 0·125 *A* going through the upper branch must also split so that twice as much current goes through the 6Ω resistor as, through the 12Ω resistor, *since the voltage across the two is the same.* Hence

$\boxed{0.042\ A}$ goes through the 12Ω resistor and

$\boxed{0\cdot084\ A}$ through the 6Ω resistor.

The results are shown in (Fig 7.34)

Example 12

A 150 *W* light bulb is connected to a 120 *V* line.

(*a*) What is the current drawn from the line ?

(*b*) What is the resistance of the light bulb while it is burning ?

(*c*) How much energy is consumed if the light is kept on for 6·0 *h* ?

(*d*) What would be the cost of this energy at 50 paise per kilo-watt-hour ?

Solution

(*a*) Since the power $P=IV$, we have

$$I=\frac{P}{V}=\frac{150\ W}{120\ V}=\boxed{1\cdot25\ A}$$

(*b*) The resistance of the light bulb is

$$R=\frac{V}{I}=\frac{120\ V}{1\cdot25\ A}=\boxed{96\Omega}$$

(*c*) $W=Pt$ where *W* is energy cousumed.

$$=(150\ W)\ (6\cdot0\ h)=900\ Wh=\boxed{0\cdot90\ kWh}$$

(*d*) cost$=0\cdot90\times50=45$ paise=**Rs.** 0·45

Example 13

A 50Ω resistor is attached to a 120 *V* circuit and immersed in 1·5 kg of water. If the current drawn from the line for 15 min, what

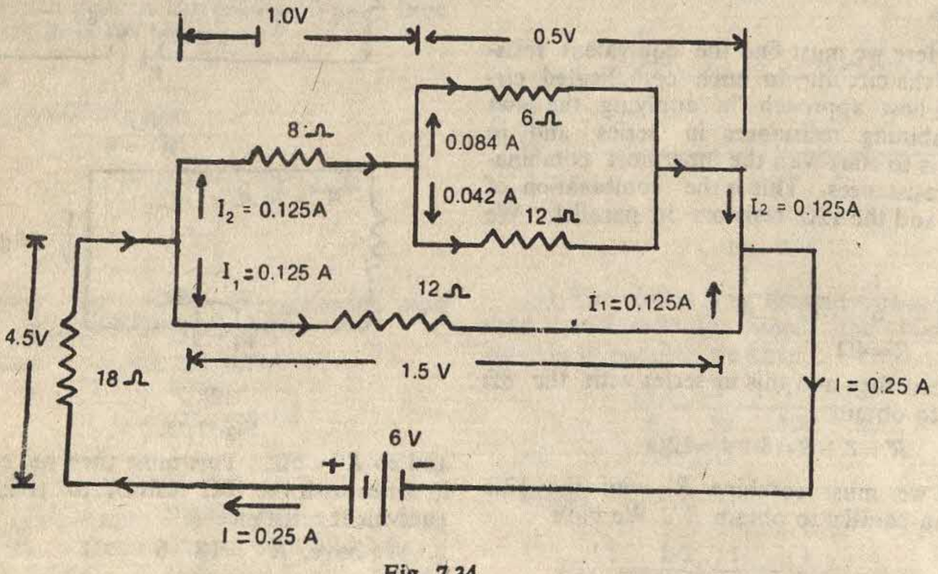


Fig. 7.34

is the increase in temperature of the water, presupposing that all the electric energy goes into heating water ? specific heat of water= 1 kcal/kg °C and 1 kcal$=4{\cdot}18\times10^3$ J

Solution.

The current drawn from the circuit is

$$I=\frac{V}{R}=\frac{120}{50}=2{\cdot}4\ A$$

The electric energy going into heating the water is then

$W=I^2Rt$ here $R=50\Omega$ and $t=15\times60s$

$$=(2{\cdot}4)^2\times50\times(15\times60)=2{\cdot}6\times10^5\ J$$

$$=\frac{2{\cdot}6\times10^5}{4{\cdot}18\times10^3}\ \text{kcal}$$

$$=62\ \text{kcal}$$

Since, Heat gained$=W=$mass of water $\times$Specific heat$\times$rise in temp. of water

$\therefore$ rise in temperature $(\triangle T)$

$$=\frac{W}{\text{mass of water}\times\text{sp. heat of water}}$$

$$=\frac{62}{1\times1{\cdot}5}=\mathbf{41°C}$$

Example 14

A heater coil connected to 220 V has a resistance of 150Ω. How long will it take this coil to heat 1 Kg of water from 20°C to 60°C, assuming that all heat is taken up by water ?

Specific heat of water$=1$ kcal/(kg°C) and 1 kcal$=4{\cdot}20\times10^3\ J$.

Solution

The current drawn from the circuit is

$$I=\frac{V}{R}=\frac{220}{150}=1{\cdot}47\ A$$

The electrical energy going into heating the water for t seconds is then

$$W=I^2Rt$$

$$=(1{\cdot}47)^2\times150\times t\ \text{joule}$$

$$=\frac{(1{\cdot}47)^2\times150\times t}{4{\cdot}20\times10^3}\ \text{kcal}$$

Since, Heat gained$=W=$mass of water$\times$ specific heat of water$\times$rise in temperature

$$\therefore\quad \frac{(1{\cdot}47)^2\times150\times t}{4{\cdot}20\times10^3}=1\times1\times40$$

$$\therefore\quad t=\frac{40\times4{\cdot}20\times10^3}{(1{\cdot}47)^2\times150}\ \text{second}$$

$$=\mathbf{518{\cdot}3\ second}$$

Example 15

Two lamps, one rated at 100 W at 220 V and the other 60 W at 220 V are connected in parallel to a 220 V supply. What current is drawn from the supply line ?

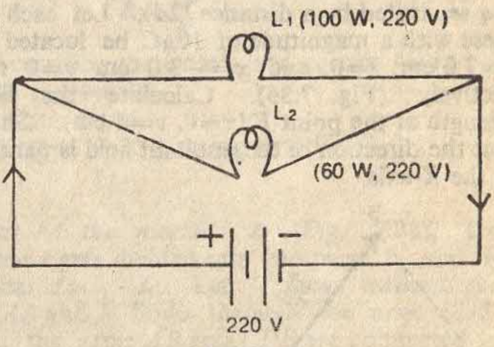


Fig. 7.35

Solution

Refer to (Fig. 7.35).

For lamp L₁

Power$=P_1=100$ W

Voltage$=V_1=220$ V

$$\therefore\quad \text{Current drawn}=I_1=\frac{P_1}{V_1}=\frac{100}{220}=\frac{5}{11}\ A$$

$\therefore$ Resistance (R_1) of the lamp

$$=\frac{V_1}{I_1}=\frac{220}{5/11}=484\Omega$$

For Lamp L₂

Power$=P_2=60$ W

Voltage$=V_2=220$ V

$$\therefore\quad \text{Current drawn}=I_2=\frac{P_2}{V^2}=\frac{60}{220}=\frac{3}{11}\ A$$

Hence, resistance (R_2) of the lamp

$$=\frac{V_2}{I_2}=\frac{220}{3/11}=\frac{2420}{3}\Omega$$

Since the two lamps are connected in parallel, their equivalent resistance (R) is given by

$$\frac{1}{R}=\frac{1}{R_1}+\frac{1}{R_2}$$

$$=\frac{1}{484}+\frac{3}{2420}=\frac{8}{2420}$$

$$\therefore \quad R=\frac{2420}{8}=\frac{605}{2}\Omega$$

The current drawn from the supply line is given by

$$I=\frac{V}{R}=\frac{220}{605/2}=\boxed{0{\cdot}727\ A}$$

Example 16

A dipole consists of two charges $+q$ and $-q$ separated by a distance $(2d)$. Let each of these with a magnitude of $10\mu C$ be located at $x=3{\cdot}0$ cm, $y=0$, and $x=-3{\cdot}0$ cm $y=0$ respectively (Fig. 7.36). Calculate the field strength at the point $P\ (x=0, y=4$ cm). Show that the direction of the resultant field is parallel to the X-axis.

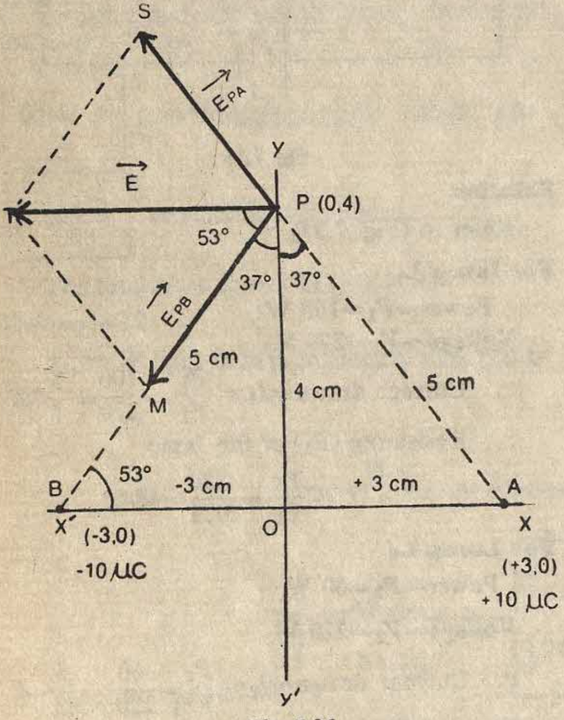


Fig. 7.36

Solution

Given $OA=+3$ cm ; $OP=4$ cm

$$\therefore \quad AP=\sqrt{(4)^2+(3)^2}=5 \text{ cm}$$

Similarly, $PB=5$ cm.

The electric field intensity at P due to $+10\mu C$ charge at A

$$=\vec{E}_{PA}=\frac{Kq}{r^2}=\frac{9\times10^9(10\times10^{-6})}{\left(\frac{5}{100}\right)^2}$$

$$=3{\cdot}6\times10^7\ N/C \text{ along } \vec{PS}$$

Let this be represented in magnitude and direction by the side $\vec{PS}$.

The electric field intensity at P due to $-10\mu C$ charge at B

$$=\vec{E}_{PB}=\frac{K(-q)}{r^2}=\frac{9\times10^9(-10\times10^{-6})}{\left(\frac{5}{100}\right)^2}$$

$$=-3{\cdot}6\times10^7\ N/C \text{ along } \vec{PM}$$

Let this be represented in magnitude and direction by the side $\vec{PM}$.

The resultant field strength $(\vec{E})$ is represented by $\vec{PT}$ according to law of parallelogram of forces.

Now $\triangle$s PST and APB are similar, therefore,

$$\frac{\vec{PT}}{AB}=\frac{\vec{PS}}{AP}$$

or $$\vec{PT}=AB\cdot\frac{\vec{PS}}{AP}$$

or $$\vec{E}=\left(\frac{6}{100}\right)\cdot\frac{3{\cdot}6\times10^7}{\left(\frac{5}{100}\right)}\ N/C$$

$$=\mathbf{4{\cdot}32\times10^7\ N/C}$$

$\because$ PT represents $\vec{E}$

$AB=6 \text{ cm}=\frac{6}{100}\ m$

PS represents $\vec{E}_{PA}$

$AP=5 \text{ cm}=\frac{5}{100}\ m$

One can easily check that the resultant field $(\vec{E})$ represented by $\vec{PT}$ is directed *parallel to the X-axis* because $\angle MPT=\angle PBO=53°$ (alternate angles)

Example 17

A battery of 6V is connected in series with three resistors of 12Ω, 6Ω, 4Ω (Fig. 7.37). Is the current passing through each of the resistors the same ? Calculate the potential difference across each resistor ?

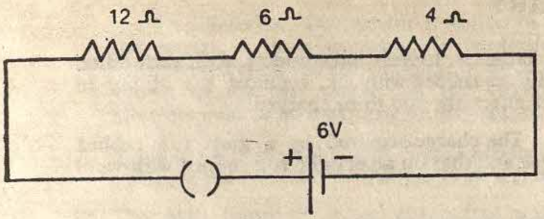


Fig. 7.37

Solution

Yes ; since the three resistors and the battery are connected in *series* so the current passing through each of the resistors *will be the same.*

Total resistance (R) in the circuit

$$=12+6+4=22\Omega$$

Total Potential difference (V)=6V

According to Ohm's law, current (I) in the circuit is given by

$$I=\frac{V}{R}=\frac{6}{22}\ A=\mathbf{0{\cdot}27\ A}$$

P.D. across 12Ω=current × resistance

$$=\frac{6}{22}\times 12=\mathbf{3{\cdot}27\ V}$$

Similarly,

$$\text{P.D. across } 6\Omega=\frac{6}{22}\times 6=\mathbf{1{\cdot}64\ V}$$

$$\text{P.D. across } 4\Omega=\frac{6}{22}\times 4=\mathbf{1{\cdot}09\ V}$$

Example 18

In the circuit shown in the Fig. 7.38, calculate

(*a*) the current flowing through the arms *AB*, *AC* and *CDE* ;

(*b*) the potential difference across *AB*, *CD* and *DE*.

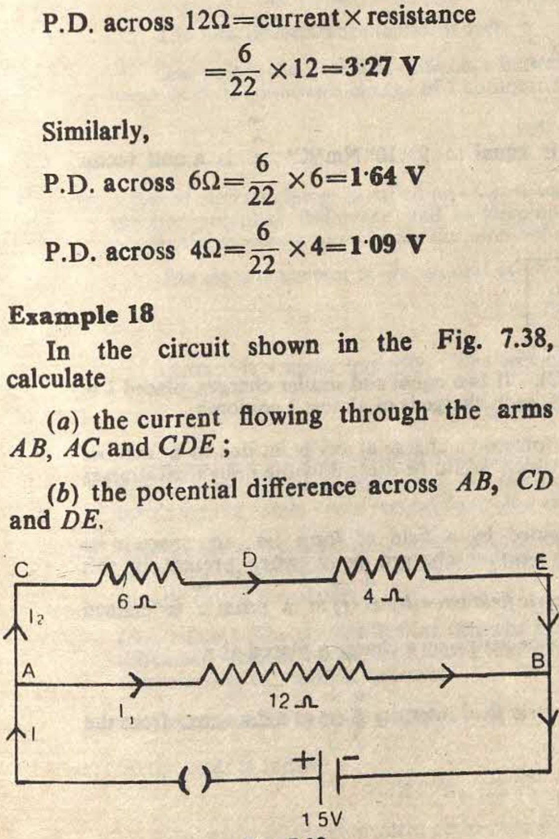


Fig. 7.38

Solution

Equivalent Resistance of the arm $CDE=6+4$ $=10\Omega$ (resistances in series).

Since the resistances 10Ω and 12Ω are *in parallel*, so the equivalent resistance (R) of the whole circuit is given by

$$\frac{1}{R}=\frac{1}{10}+\frac{1}{12}=\frac{11}{60}$$

or $$R=\frac{60}{11}\ \Omega$$

According the Ohm's law, current (I) in the circuit is given by

$$I=\frac{V}{R}=\frac{1{\cdot}5}{\frac{60}{11}}=\frac{1{\cdot}5\times 11}{60}=0{\cdot}275\ A$$

(*a*) At the junction *A* (Fig. 7.38), the current I gets divided into two parts I_1 and I_2 so that $I=I_1+I_2$. Let I_1 flows through the arm *AB* and I_2 flows through the arm *CDE*. Since the arms *AB* and *CDE* are connected *in parallel* so the potential difference across the arms *AB* and *CDE* each *is the same.*

Hence

$$12\times I_1=10\times I_2 \qquad \text{(Ohm's law } i.e., V=IR)$$

$$\therefore \quad \frac{I_1}{I_2}=\frac{10}{12}$$

or $$\frac{I_1}{I_1+I_2}=\frac{10}{10+12}$$

or $$\frac{I_1}{I}=\frac{10}{22}$$

$$\therefore \quad I_1=\frac{10}{22}\times I=\frac{10}{22}\times 0{\cdot}275=\mathbf{0{\cdot}125\ A}$$

The current flowing through the arm

$$AB=\mathbf{0{\cdot}125\ A}$$

Now, $I_2=I-I_1$

$$=0{\cdot}275-0{\cdot}125=\mathbf{0{\cdot}15\ A}$$

Thus the current flowing through the arms *AC* and *CDE*=**0·15 A** as they are connected *in series.*

(*b*) **P.D. across the arm *AB***

=current × resistance

$$=0{\cdot}125\times 12=\mathbf{1{\cdot}5\ V}$$

P.D. across the resistor

CD=current × resistance

$$=0{\cdot}15\times 6=\mathbf{0{\cdot}9\ V}$$

P.D. across the resistor

$$DE=\mathbf{0{\cdot}15\times 4=0{\cdot}6\ V}$$

SUMMARY

1. Simplest method of producing an electric charge is to rub two bodies with each other. Ebonite or plastic objects rubbed with wool and glass rubbed with silk, acquires the ability to attract small objects and the bodies showing this effect are said to be charged.

2. There exist only two kinds of electrical charges. The charge acquired by a glass rod rubbed with silk is, by convention, called *positive charge* and that on an ebonite rod rubbed with wool is called *negative charge*.

3. Like charges repel each other while unlike charges attract each other.

4. According to the principle of conservation of electric charge, the electric charge is always conserved. It can neither be created nor destroyed. It can only be transferred from one material to another.

5. The materials in which charges move easily are called *Conductors* and those in which charges seem to be bound as *insulators*.

6. The phenomenon of charging a neutral conductor by bringing another charged conductor near it, is known as electric induction. The quantity of charge induced on a neutral conductor increases (*i*) with the charge on the inducing body and (*ii*) with the decrease in the distance between the two. The induced negative and positive charges are equal in amount and each is equal to the inducing charge.

7. *Charging electroscope by induction.* Bring the charged rod near to the disc (or the cap) where upon the leaves diverge; touch the disc, the leaves collapse; remove the finger, the leaves remain closed; finally remove the rod, the leaves diverge. The induced charge on the leaves is *opposite* to the inducing charge on the rod.

8. *Coulomb's Law.* The force of attraction or repulsion between two charged bodies carrying charge q_1 and q_2 and separated by a distance r in vacuum (or air) is given by

$$\vec{F}=K\frac{q_1q_2}{r^2}\,\hat{\vec{r}}$$

where K is constant of proportionality and is equal to $9\times10^9\ \mathrm{Nm^2/C^2}$; $\hat{\vec{r}}$ is a unit vector along $\vec{r}$.

In magnitude,

$$\boxed{F=K\frac{q_1q_2}{r^2}}$$

9. The unit of electric charge is a *coulomb* (C). If two equal and similar charges, placed 1 m apart, repel each other with a force of 9×10^9 N, each charge is of almost 1 coulomb.

10. According to the *principle of superposition*, the force on a charge at any point due to a number of other charges is the *vector sum* of the forces which would be exerted by the individual charges on the charge at that point.

11. A charged body can be regarded as surrounded by a field of force *i.e*, the space in its neighbourhood is changed in such a way that another charged body, when present in this region, will experience a force. In general, *electric field intensity* $\vec{E}(\vec{r})$ at a point $\vec{r}$ is defined such that $q\vec{E}(\vec{r})=\vec{F}(\vec{r})$ where $\vec{F}$ is the electric force acting on a charge q placed at r.

From Coulomb's law it follows that the electric field intensity $\vec{E}(\vec{r})$ at a distance r from the point charge q situated at the origin is

$$\vec{E}(\vec{r})=\frac{Kq}{r^2}\,\hat{\vec{r}}$$

The direction of the vector $\vec{E}$ is that of the force on the *unit positive charge*. In S.I. units, the electric field is expressed in newton/coulomb. The charge q is the source of the electric field and is called the *source charge* and the charge which feels the influence of the field is known as the *test charge*. A test charge is taken to be *vanishingly small* so that it does not alter the field to be measured by any appreciable extent.

When there is more than one charge producing the field, we use the superposition principle to calculate the resultant field intensity at a given point.

12. The path traced by a test charge free to move under the effect of an electric field is called an *electric line of force*. Thus a line of force is a curve so drawn that a tangent to it at any point gives the direction of the electric field at that point.

By convention, electric lines of force originate from a positively charged body and end at the negatively charge one.

No two lines of force intersect each other.

13. A charge in an electric field experiences a force and in response to this the charge moves, work is done by the source of the field. If, however, the charge is moved *against* the force, work is done by an outside agency.

When a charge in an electric field moves from one point to another, the two points are said to differ in *electric potential*. We define the *electric potential difference* between the two points A and B as the work done to move a unit charge from A and B.

$$\text{Potential difference } (V)=\frac{\text{work done } (W)}{\text{charge } (Q)}$$

or

$$\boxed{W=VQ}$$

The unit of electric potential is *volt*.

One volt is the potential difference between two points in an electric field when 1 joule of work is done to move a charge of 1 coulomb from a less positive to a more positive point.

$$1 \text{ volt}=\frac{1 \text{ joule}}{1 \text{ coulomb}}$$

14. Flow of electric charge is called an *electric current*. Electric current flows when there is an electric potential difference and to keep an electric current flowing through a conductor, it is obviously necessary *to maintain the potential difference* between its ends.

The electric current is the amount of charge passing through a given point in one second.

$$I=\frac{Q}{t}$$

Current is a *scalar* quantity. The unit of elecric current is *ampere* (A).

$$1 \text{ ampere}=\frac{1 \text{ coulomb}}{1 \text{ second}}$$

One electron carries a charge of $1{\cdot}6\times10^{-19}$ C and a current of one ampere corresponds to a flow of $6{\cdot}3\times10^{18}$ electrons/second. In fact there is a *drift* of so many electrons (not necessarily involving the same) every second from one end of the wire to the other.

15. The property of a conductor which affects the flow of current in it is called its *resistance*. It is expressed in volt/ampere, or *ohm* (symbol Ω). A conductor possessing a certain resistance is usually called a *resistor*.

16. *Ohm's Law*. The current flowing through a conductor is directly proportional to the potential difference across its ends provided the physical conditions of the conductor *e.g.* density, temperature, etc. remain constant.

Mathematically ; $\frac{V}{I}=R$ or $V=IR$

17. *Resistances in series*:

$$R=R_1+R_2+R_3+\ldots.$$

The value of the equivalent resistance R is equal to the sum of the resistances in series.

Resistances in parallel :

$$\frac{1}{R}=\frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3}+\dots$$

The reciprocal of the equivalent resistance is the sum of the reciprocals of the resistances.

18. The resistance of a given wire depends upon
    (*i*) the material of the wire,
    (*ii*) the length of the wire, and
    (*iii*) the area of cross-section of the wire.

    Expressed mathematically, it implies that

$$R=\rho\frac{l}{A} \text{ where } \rho=\text{resistivity of the material.}$$

19. *Resistivity* (or *specific resistance*) of a material is defined as the resistance of a cube of the material of side 1 m when current flows perpendicular to opposite faces. It is expressed in *ohm m.*

20. Amount of *heat generated* $H=\frac{I^2Rt}{4{\cdot}18}$ cal$=I^2Rt$ joule

    Electric power $(P)=\frac{W}{t}=I^2R=VI$ watt

    kilo-watt-hour (kWH) is the unit of energy.

    1 kWH$=3{\cdot}6\times10^6$ J

21. Electroplating is essentially depositing electrically a coating of any desired metal on another metal object. The process of electrolysis is made use of in the production of aluminium, copper, magnesium and other metals.

QUESTIONS

[A] Objective Type Questions

1. **Complete the following :**

(*a*) 1 volt=.........joule per.........
(*b*) I mV=.........V
(*c*) 1 μV=.........V
(*d*) 1 kV=.........V
(*e*) 1 MV=.........V
(*f*) 1 eV=.........joule
(*g*) Electric field Intensity=K.........where K=........ newton per.........
(*h*) 1 coulomb=.........electrons
(*i*) Charge on an electron=............
(*j*) An electron volt is a unit of............
(*k*) The Unit of electric field is S.I. system is............

2. The expression for Coulomb's Law of force of interaction between two charges is

(*a*) $\frac{K\,q_1q_2}{r^2}$

(*b*) $\frac{K\,q_1r^2}{q_2}$

(*c*) $\frac{q_2}{K\,q_1r^2}$

(*d*) $\frac{K\,q_1q_2}{r}$

(*e*) $\frac{q_1q_2}{r}$

3. An ebonite rod rubbed with a piece of flannel acquires.

   (*a*) Positive charge
   (*b*) Negative charge
   (*c*) North poles
   (*d*) South poles

4. A negatively charged object is one that has an excess of

   (*a*) Positive charge
   (*b*) Negative charge
   (*c*) South poles
   (*d*) North poles

5. A charged rod *A* is brought near another negatively charged rod *B*. It is observed that the negatively charged rod *B* gets repelled this indicates that the first charged rod *A* is

   (*a*) Charged negatively
   (*b*) Charged positively
   (*c*) Not charged and not magnetized
   (*d*) Magnetized but not charged

6. The fundamental particle in an atom which is readily transferred from one object to another is the

   (*a*) Proton
   (*b*) Electron
   (*c*) Neutron
   (*d*) Positron

7. The work needed to move an electric charge between two points is measured in units known as

   (*a*) coulombs
   (*b*) watts
   (*c*) joule
   (*d*) amperes

8. Two point charges repel each other with a force $9{\cdot}0\times10^{-5}$ newtrons when they are 1·0 metre apart. We can be sure of that both charges are

   (*a*) Negative
   (*b*) Positive
   (*c*) Unlike
   (*d*) Like

9. If the distance between two charges in Q (8) is increased to 3·0 meters, the force between the charges becomes, in newtons

   (*a*) $1{\cdot}0\times10^{-5}$
   (*b*) 27×10^{-5}
   (*c*) $3{\cdot}0\times10^{-5}$
   (*d*) $4{\cdot}5\times10^{-5}$

10. Two point charges are a distance of r meters apart and exert a force of F on each other. If the distance between them is *doubled*, the force becomes

(*a*) $F/4$
(*b*) $F/2$
(*c*) $F/2r$
(*d*) F

11. Most metals are good conductors of electricity because they have

(*a*) A large number of molecules
(*b*) A large number of free electrons
(*c*) A shiny surface
(*d*) A low temperature coefficient

12. As the electric field intensity at certain point decreases, the force per unit charge at the point

(*a*) increases
(*b*) decreases
(*c*) remains the same

13. When two materials such as glass and silk, are rubbed together, the net charge on one material, after rubbing, is numerically

(*a*) less than that of the other
(*b*) greater than that of the other
(*c*) the same as the other

14. Six joules of work are required to transfer 12 coulombs between two points. The potential difference, in volts, between the two points is

(*a*) 0·5
(*b*) 2
(*c*) 12
(*d*) 72

15. The force between two charges is 48 newtrons. If the distance between the charges is halved, and each charge is doubled, the force, in newtons, will be

(*a*) 12
(*b*) 24
(*c*) 48
(*d*) 48×16

16. The SI unit of electric potential is the

(*a*) volt
(*b*) Voltmeter
(*c*) Microvolt
(*d*) coulomb

17. Solids which are good conductors of electricity have many loosely bound

(*a*) Protons
(*b*) Electrons
(*c*) Atoms
(*d*) Neutrons

18. A unit of electric current is the

(*a*) volt
(*b*) watt
(*c*) ampere
(*d*) coulomb

19. To keep an electric current flowing through a conductor, it is necessary to maintain.

(*a*) the potential difference between its ends.
(*b*) the capacity of the conductor
(*c*) the quantity of charge
(*d*) the ratio between potential difference and charge

20. A 30 ohm and a 60 ohm resistors are connected in series. The current in the 60 ohm resistor is how many times that in the 30 ohm resistor ?

(*a*) 1
(*b*) 2
(*c*) 1/2
(*d*) 4

21. A man has two nichrome wires each 3 m long. One wire has a cross-section area of 4 units, the other a cross-section area of 8 units. The resistance of the first wire is............times that of the second.

(*a*) 1/2
(*b*) 2
(*c*) 1/4
(*d*) 4

22. Two copper wires have the same cross-section but one wire is three times as long as the first. The ratio of the resistance of the long wire to that of the shorter one is

(*a*) 1/3
(*b*) 1/9
(*c*) 3
(*d*) 9

23. A 30 ohm and a 60 ohm resistor are connected in series. The combined resistance of the two resistors, in ohms, is

(*a*) 20
(*b*) 90
(*c*) 30
(*d*) 1800

24. Two wires are made of nichrome. Wire A is twice as along as wire *B* and has a cross-section area twice a great. The ratio of the resistance of wire *A* to that of wire *B* is

(*a*) 1
(*b*) 2
(*c*) 3
(*d*) 1/2
(*e*) 4

25. The current in a 60 ohm resistor connected to a battery of negligible resistance having an emf (P.D.) of 30 volt is......

26. The voltage across a resistor of 20 ohm, with a current in it of 3·5 ampere——

27. A 20-ohm and a 40-ohm resistor are connected in paralled. The current in the 40-ohm resistor is how many times that of the 20-ohm resistor ?

(*a*) 1
(*b*) 2
(*c*) 4
(*d*) 1/2

28. If the potential difference across a resistor is doubled, the current in it is

(*a*) unchanged
(*b*) doubled
(*c*) halved
(*d*) quadrupled

29. As more appliances are added in parallel to a battery of negligible internal resistance, the voltage across each appliance

(*a*) increases
(*b*) decreases
(*c*) remains the same

30. Two charged bodies *A* and *B* are at potential —30 V and +20 V respectively and they are connected by a conducting wire. The current

(*a*) will flow from *A* to *B*
(*b*) will flow from *B* to *A*
(*c*) will not flow at all

31. A charge of 120 coulomb flows across a point in 4 minutes. The flow of an electric current, in ampere is

(*a*) 5
(*b*) 0·5
(*c*) 1/5
(*d*) 25

32. A 2-ohm resistor and a 4-ohm resistor are connected in parallel. The combined resistance of the two resistors, in ohm, is

(*a*) 13·3
(*b*) 133
(*c*) 1·33
(*d*) 1330
(*e*) 0·133

33. The unit of specific resistance is

(*a*) ohm-meter
(*b*) ohm
(*c*) volt
(*d*) ampere

34. 1 volt of petential difference is equal to

(*a*) 1 coulomb per joule
(*b*) 1 joule
(*c*) 1 joule per coulomb
(*d*) 1 ampere per joule

35. A 20-ohm and a 40-ohm resistor are connected in series. The ratio of the power used by the 40-ohm resistor to that used by the 20-ohm resistor it

(*a*) 1
(*b*) 2
(*c*) 1/2
(*d*) 4

36. A 20-ohm and a 40-ohm resistor are connected in parallel. The power used by the 40-ohm resistor is how many times that of the 20-ohm resistor ?

(*a*) 1/2
(*b*) 2
(*c*) 1/4
(*d*) 4

37. For the resistors in Q. (36) the rate at which heat is developed in the 40 ohm resistor is how many times that the 20-ohm resistor ?

(*a*) 1/2
(*b*) 2
(*c*) 1/4
(*d*) 4

38. If a potential difference across a resistor is doubled, the power used by it is

(*a*) unchanged
(*b*) doubled
(*c*) halved
(*d*) quadrupled

39. Several electrical appliances are arranged in order to decreasing wattage rating. Assuming that they are rated at 120 volts, as the wattage rating decreases, the resistance of the appliances

(*a*) increases
(*b*) decreases
(*c*) remains the same.

40. A 100-watt heater operates on 120 volts. The current in the heater is...... amperes.

41. Of the following, the meter which reads energy used, is the

(*a*) ammeter
(*b*) voltmeter
(*c*) ohm meter
(*d*) kilo-watt-hour meter

42. $3{\cdot}6 \times 10^6$ joules of energy represent
    - (*a*) watt-hour
    - (*b*) kilo-watt hour
    - (*c*) watt
    - (*d*) H.P.

43. When a current of I amperes flows through a resistor of R ohms, the rate of production of heat is
    - (*i*) I^2R joule per second
    - (*ii*) I^2R watt
    - (*iii*) I^2R coulomb per volt

44. Electrical *induction* is the process of
    - (*a*) charging a polythene rod negatively by rubbing it with a duster
    - (*b*) charging an acetate rod positively by rubbing it with a duster
    - (*c*) charging a body positively by contact with a positive rod
    - (*d*) charging a body negatively by contact with a negative rod
    - (*e*) producing a separation of equal amounts of positive and negative charges without contact.

[B] Very Short Answer-Type Questions :

1. What property do electrical objects have ?
2. What is Coulomb's law of charges ?
3. How does a charge on an electron compare with the coulomb ?
4. What kind of charge is acquired by a neutral object when it touches a positive object ?
5. Is electric field intensity a scalar quantity ?
6. What is one ampere ?
7. What does the electric current consist of in metals ?
8. State ohm's law.
9. What is one ohm ?
10. What is a milliampere ?
11. What is the effect of each of the following on the resistance of a metallic conductor
    - (*a*) doubling the length
    - (*b*) doubling the cross-section area
    - (*c*) increasing the temperature.
12. What is meant by a closed circuit ?
13. What is the potential difference across one of the resistors in a series circuit ?
14. What is the combined resistance of resistors connected in parallel ?
15. What is a voltmeter ? How is it connected in an electrical circuit ?
16. What is an ammeter ? How is it connected in an electrical circuit ?

17. Name the S.I. unit of
    - (*a*) charge
    - (*b*) current
    - (*c*) potential difference
    - (*d*) resistivity
18. What is the relationship between coulomb and ampere ?
19. How is the energy used by a device related to its power rating ?
20. If two unequal resistors are connected in parallel, which resistor develops heat at the greater rate ?
21. Name three appliances which are based on the heating effect of current.
22. Name the S.I. unit of
    - (*a*) Electrical energy
    - (*b*) Electric power
    - (*c*) Electrical energy used
23. How are electrical appliances connected in a house ?
24. What is earthing ?
25. What is electrolysis ?
26. What is electroplating ?
27. What is a voltaic cell ?
28. Define resistivity.
29. Define volt.
30. What is bigger, a coulomb or charge on an electron ?
31. How many electronic charges form one coulomb of charge ?

33 Two bodies having one coulomb of charge each is separated by 1 m in air. What is the force of repulsion between them ?

34. State two practical applications of chemical effect of current. [*A.I.S.S. 1987*]

[C] Short Answer Type and Essay Type Questions

1. State coulomb's law of force of interaction between two charges and hence define coulomb (a unit charge). [*A.I.S.S. 1982*]
2. (*a*) Define : Electric field and Electric field intensity
    - (*b*) Is electric field intensity a vector or a scalar quantity ?
    - (*c*) Mention its unit in SI system.
    - (*d*) Derive an expression for the magnitude of electric field intensity at a point in an electric field.
3. What determines whether a difference of potential exists between two points ?
    - (*b*) Define (*i*) potential difference
      (*ii*) Volt
    - (*c*) Is potential (or potential difference) a vector or a scalar quantity ?
    - (*d*) A conducting object connected to the earth is at zero potential. Explain.

4. Derive an expression for the amount of heat produced in a conductor when an electric current flows through it.

5. What is meant by power and energy in an electric circuit? How are these measured? What is meant by one unit of electricity.

6. Define; watt, kilowatt-hour and kilo-watt.

7. Describe clearly the processes of friction and induction to charge a body. Explain how a charged (positive or negative) body attracts an uncharged body.

8. State the principle of conservation of charge. Describe two experiments to illustrate this principle.

9. Distinguish between conductors and insulators.

10. How would you use Coulomb's law to calculate the force on a charged body in the presence of many other charged bodies?

11. Name three quantities that are measured in electrcity and state in what units they are measured.

12. (*a*) Define: Electric potential difference; Electric current; an ampere; coulomb; volt and ohm.

    (*b*) What is the relationship between charge and current?

    (*c*) Complete the following :—

    (*i*) 1 coulomb=......electrons

    (*ii*) 1 mA=......A

    (*iii*) 1 μA=......A

    (*iv*) 1 mV=......V

    (*d*) Explain the meaning of the statement, "Potential difference between two points is 1 volt." (*A.I.S.S. 1982*)

13. State the use of the following electrical instruments in an electric circuit:

    (*a*) Ammeter

    (*b*) Voltmeter

    (*c*) Rheostat

    (*d*) Key

    (*e*) Cell or battery

    (*f*) Connecting wires.

14. Draw the following circuit:

    A battery of 3 cells supplies current to a circuit in which a given wire is connected in series with a lamp, a rheostat (variable resistance), a plug key and an ammeter; a voltmeter is now connected across the given wire to measure the potential difference between its ends.

15. State Ohm's Law. Draw an electrical circuit with which you can verify this law and make out a table showing the readings required for this experiment. Name two physical conditions that influence the resistance of the conductor.

15. (*a*) Define resistance of a conductor. Mention its unit and define it also

    (*b*) What is the difference between a rheostat and a resistance box?

16. Calculate the total resistance when a number of conductors are joined

    (*a*) in series, and

    (*b*) in parallel.

18 (*a*) What is an electric circuit ?

(*b*) If one bulb gets fused in your house, will other bulbs remain glowing ? Why ?

(*c*) Write down the full names and nationalities of the scientists after whom the following units are named.

The ampere : the volt ; the ohm. (Find these out from books in your school library.)

19. Connect two lamps (each 1·5 *V*), a battery (1·5 *V*) and a switch so that one lamp remains permanently alight and the other lamp be switched on and off by the switch.

20. Connect the two lamps, two switches and a battery so that both switches are required to switch on both lamps, but one switch will switch off one lamp and other switch will switch off both lamps.

21. (*a*) Mention the various factors that affect the resistance of a conductor.

(*b*) What do you understand by the specific resistance (or resistivity) of the material of conductor ?

(*c*) State SI unit of specific resistance of a conductor.

22. (*a*) How does the resistance of a conductor vary with its length ?

(*b*) What is the relationship between the resistance of a conductor and its cross-sectional area ?

23. The resistance wire in an electric radiator is usually wound on fireclay an insulating material ? Why is an insulating material used ? What would happen if a bare resistance wire were wound on a piece of iron ?

24. Some materials conduct electricity ; for example piece of iron or copper. Others like paper, do not appear to conduct, and we call them insulators. Wood is an insulator. It might be a good material on which to wind the resistance wire of the electric radiator element, but it is not. Why not ?

25. Why does the resistance wire get hot and not the copper wire of the cable of the electric immersion heater ?

26. What is meant by electrical induction ? Show how will you charge a body positively by induction. Why is the finger removed before the charged body ?

27. (*a*) Define an electric line of force.

(*b*) Give the chief properties of electric lines of force.

(*c*) Explain the electrostatic attraction and repulsion on the basis of the lines of force.

(*d*) Why two electric lines of force do not cross each other ?

28. (*a*) How can electron-transfer reactions that are not spontaneous be forced to occur ?

(*b*) What are the basic requirements for a silver plating cell ?

29. A very small sphere is given a positive charge and is then brought near a large negatively charged plate. Draw a diagram of the system showing the appearance of the electric lines of force.

30. How can you explain (*a*) the presence of a charge on a glass rod after it has been rubbed with silk, (*b*) the charge remaining on the silk ?

31. An insulated, uncharged sphere A stands near a wall, a positively charged sphere is placed so that A is between it and the wall. Draw a diagram of the electric lines of force round the arrangement.

PROBLEMS

1. What is the electric field intensity 0·4 m from a charge of 7×10^{-5} coulomb ? **[Ans.** $3{\cdot}93 \times 10^{6}$ N/C]

2. Two charges, one of 1·5 μC and the other of 3 μC are 0·2 m apart. Where is the electric field in their vicinity equal to zero ? **[Ans.** 0·0828 m from the smaller one]

3. Hydrogen atom, which is the simplest structure of all atoms, consists of an *electron* (a particle of mass $9{\cdot}1 \times 10^{-31}$ kg and a negative charge of $1{\cdot}6 \times 10^{-19}$ C) and a *proton* (a particle of mass $1{\cdot}7 \times 10^{-27}$ kg and a positive charge of $1{\cdot}6 \times 10^{-19}$ C) separated by an average of $5{\cdot}3 \times 10^{-11}$ m. Compare the electrical force between the electron and proton and compare it with the gravitational force between them. Universal gravitational constant $(G) = 6{\cdot}7 \times 10^{-11}$ Nm²/kg². **[Ans.** $8{\cdot}1 \times 10^{-8}$ N ; $2{\cdot}2 \times 10^{39}$]

4. Charge $Q_1 = +1{\cdot}00 \times 10^{-12}$ C and $Q_2 = -4{\cdot}00 \times 10^{-12}$ C are situated 5 m apart in air. A third charge $Q_3 = +1{\cdot}00 \times 10^{-14}$ C is placed midway between them. Find the magnitude and direction of the resultant force on the third charge. **[Ans.** $7{\cdot}20 \times 10^{-17}$ N in the direction from Q_1 to Q_2]

5. Determine the electric field intensity midway between charges of $+1{\cdot}00 \times 10^{-12}$ C and $-4{\cdot}00 \times 10^{-12}$ C which are separated by 5 m in air. **[Ans.** $7{\cdot}20 \times 10^{-3}$ N/C in the direction from the smaller charge to the larger one]

6. Two point charges of magnitude 4×10^{-8} C and -9×10^{-8} C are 50 cm apart in vacuum. At what point is the electric field intensity zero ? **[Ans.** 1 m from the positive charge]

7. Two equal conducting spheres of negligible size are charged with $5{\cdot}0 \times 10^{-14}$ coulomb and $-6{\cdot}0 \times 10^{-14}$ coulomb, respectively, placed with their centres 20 cm apart. If they are moved to positions 50 cm apart, compare the forces between them in the two positions. The spheres are connected by a thin wire. What force does each now exert on the other ? **[Ans.** 6·25 to 1 ; 9×10^{19} N]

8. A body whose mass is 10^{6} kg carries a charge of $+10^{-6}$ C. What is the magnitude of an electric field that can hold the body suspended in equilibrium ? Acceleration due to gravity = 10 m/s². **[Ans.** 10 N/C]

9. Three charges +5 μC, -4 μC and +4 μC are placed at the vertices A, B, D respectively of an equilateral triangle whose one side is 10 cm. Find the resultant force on the charge at A, due to the other two charges. **[Ans.** 18 N directed parallel to DB]

10. A point charge A of $+4 \times 10^{-8}$ C is placed at a distance of 0·5 m from a charge B of -3×10^{-8} C. Find the electric field intensity at the point midway between the charges. **[Ans.** $10{\cdot}08 \times 10^{3}$ N/C]

11. Find the force on a test charge of 2×10^{-9} C if it is placed in a uniform field intensity of 5×10^{4} N/C. Calculate the work done by the field if the charge moves 0·3 m (*a*) in the direction of the field, and (*b*) perpendicular to the field. **[Ans.** 1×10^{-4} N ; (*a*) 3×10^{-5} joules (*b*) zero]

12. If 10 *A* of current flows through a conductor for 1 minute, how many units of charge pass through it in 1 minute ? **[Ans.** 6×10^{2} C]

13. A dry cell is directly connected by wires to a small light bulb. The cell maintains a potential difference of 1·5 V across the lamp. If the electron current flowing through the circuit is 0·5 A, what is the resistance of the circuit ? **[Ans** 3 ohm]

·14. Three resistances of 5, 10 and 20 ohms are connected (*i*) in series, and (*ii*) in parallel. Find the effective resistance in each case. **[Ans.** (*i*) 35 Ω (*ii*) 2·85 Ω]

15. What is the resistance of a copper wire 20 cm long and 0·81 mm in diameter at 20°C ? The resistivity (or specific resistance) of copper at 20°C is $1{\cdot}72\times10^{-6}$ ohm.cm. [Ans. 0·67 ohm]

16. A rectangular bar of iron is 2 cm by 2 cm in cross-section and is 40 cm long. Its resistance is 1×10^{-4} ohm at 20°C. What is the specific resistance of the rectangular bar of iron ? [Ans. 1×10^{-7} ohm.m]

17. What resistance must be placed in parallel with an 11 ohm coil in order to make the combined resistance 19 ohms ? [Ans. 110 Ω]

18. Three resistance wires 5, 4, 10 ohms respectively are connected in parallel in an electric circuit. If the current in the 4 ohm branch is 20 mA, calculate the currents in other branches. [Ans. 16 mA ; 8 mA]

19. Three resistances of 20 ohm, 5 ohm and 4 ohms respectively are connected in parallel. Find the combined resistance and total current when a potential difference of 5·8 V is applied. [Ans. 2 Ω ; 2·9 A]

20. Two coils in series have a resistance of 18 Ω and in parallel a resistance of 40 Ω. Find the separate resistances. [Ans. 12 Ω ; 6 Ω]

21. What current passes through *R* in Fig. (7.39) ? [Ans. 1 A]

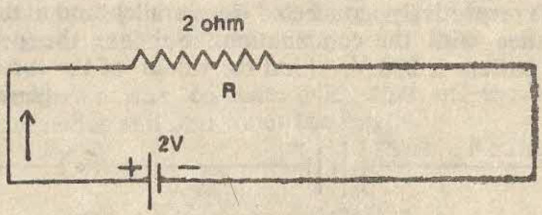


Fig. 7.39.

22. What is *R* in (*a*) and (*b*) in Fig. (7.40) ? [Ans. (*a*) 5 Ω (*b*) 13·3 Ω]

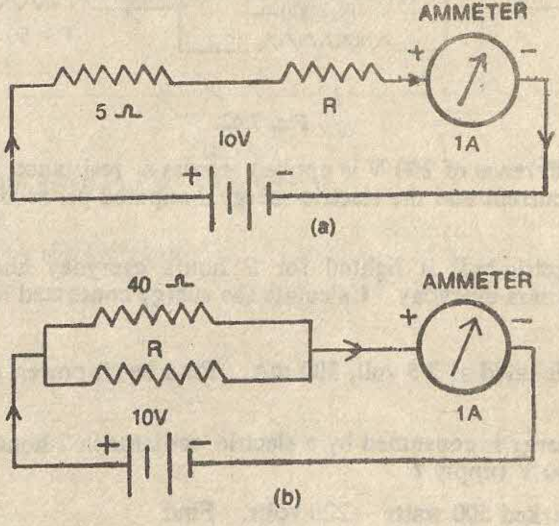


Fig. 7.40.

23. How much work is done in moving a charge of 2 coulomb from a point 118 at volts to a point at 128 volts ? [*A.I.S.S. 1982*]
[Ans. 20 J]

24. In the circuit diagram given in Fig. (7.41) find ;

(*i*) total resistance of the circuit
(*ii*) total current flowing in the circuit
(*iii*) the potential difference across R_1

]*A.I.S.S. 1982*]
[Ans. (*i*) 12 ohm (*ii*) 0·5 A (*iii*) 3·6 V]

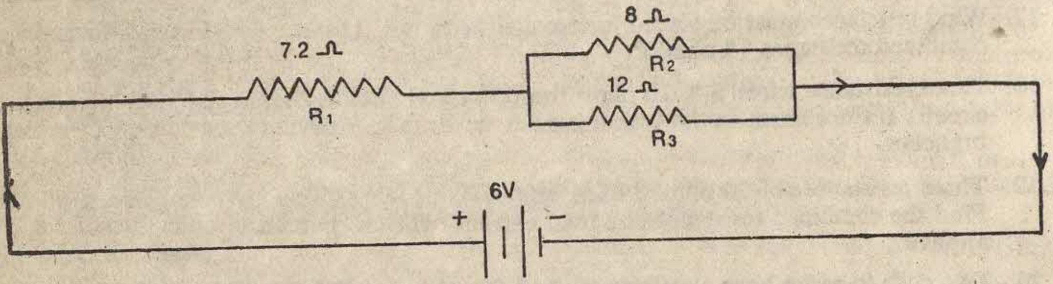


Fig. 7.41.

25. Consider a circuit shown in Fig. (7.42). Here we have two resistances R_1 and R_2 of 100 Ω and 300 Ω respectively connected in parallel and a third resistance R_3 of 50 Ω connected in series with the combination. Suppose the potential drop across the terminals of the battery is 200 V. Find the values of the currents through the resistors R_1, R_2 and R_3. **[Ans.** 1·2 A ; 0·4 A ; 1·6 A]

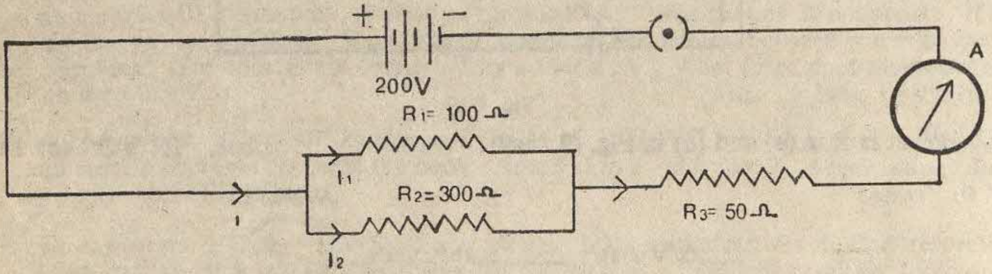


Fig. 7.42.

26. A potential difference of 200 V is applied across a resistance of 400 Ω in a light bulb. Calculate the current and the electric energy dissipated per second.
[Ans. 0·5 A ; 100 J]

27. A 100 watt electric bulb is lighted for 2 hours everyday and four 40 watt bulbs are lighted for 4 hours everyday. Calculate the energy consumed in a month (30 days).
[Ans. 25·2 kWh]

28. A torch bulb is rated at 2·5 volt, 300 mA. Find its (*i*) power, and (*ii*) resistance.
[Ans. 1·25 W ; 5 Ω]

29. How much energy is consumed by a electric radiator in 2 hours, if it takes a current of 5 A from a 200 V supply ? **[Ans.** 2 kWh]

30. A heater is marked 500 watts − 220 volts. Find

(*i*) the current it draws
(*ii*) the cost of using it for 4 hours at 15 paise per unit ; and
(*iii*) the resistance of the heater. **[Ans.** (*i*) 2·27 A (*ii*) 30 paise (*iii*) 96·8 ohm]

31. An electric kettle takes 4 A when put on a circuit of 220 V. In what time will 450 g of water be heated from 20° C to 100°C ? (1 calorie = 4·2 joule).
[Ans. 171·8 seconds]

32. A house is fitted with 8 lamps (each 40 W) and 2 fans (each taking 0·25 A). The energy is supplied by electric company at 220 V. If the lamps are (on the average) lighted for three hours a day and the fans work for 6 hours a day what will be the bill for 30 days ? The cost of energy supplied is 40 paise per kWh. [Ans. Rs. 19·44]

33. An electric coil of 45 Ω resistance is connected to an electric supply of 220 V. Compare the heat energy involved with that produced in the coil when it is joined (*i*) in series (*ii*) in parallel with similar coil and connected to the same supply.
[Ans. (*i*) 2 : 1 (*ii*) 1 : 4]

34. Three lamps of 100 W, 70 W and 50 W respectively are connected to a power supply of 220 V. Calculate

(*i*) total current consumption
(*ii*) total resistance of the arrangement
(*iii*) cost of keeping it lighted for 5 hours daily for 30 days ; the cost of electricity being 25 paise per unit. [Ans. (*i*) 1 A (*ii*) 220 Ω (*iii*) Rs. 8·25]

35. A 1400 W room heater is used for 10 hours daily. If the energy be 10 paise per unit, what is the cost of using it for a month of 30 days ? How much heat in calories is supplied by it per hour ? (1 Cal = 4·2 J). [Ans. Rs. 42·00 ; 12 × 10⁵ cal]

36 How does the resistance of a wire compare with that of another wire of the same material but twice the radius and four times the length ? *[A.I.S.S, 1987]*
[Ans. Resistance remains the same**]**

37

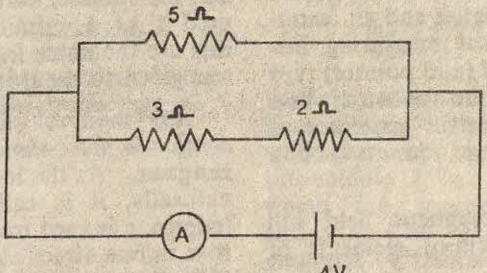


Fig. 7.43.

In the circuit diagram given in Fig. 7.43, find

(*i*) Total resistance
(*ii*) Current shown by the ammeter A. *[A.I.S.S. 1987]*
[Ans. (*i*) 2·5 Ω (*ii*) 1·6 A**]**

CHAPTER 8

Magnetism and Electromagnetism

8.1. INTRODUCTION

In this chapter you will see that a magnet does other things besides merely picking up nails and pins, a property which you probably know already. You will also learn that iron that steel are not the only metals that can be magnetised. You will also see why a piece of iron becomes a magnet under the influence of a magnet brought near it.

When an electric charge is still, there is an electric field around it. When the charge moves, a magnetic field also appears. Associated with any current is a magnetic field ; they are inseparable. Because of the magnetism associated with a current, there is an interaction between a current-carrying wire and a magnetic field much like the one that occurs between an ordinary bar magnet and an external magnetic field. Electrical measuring instruments of the moving coil (and pointer) type make use of this effect. In the industrial uses you will learn about an electric generator, a transformer, household electric circuits and a fuse.

Importance of earth's magnetic field will also be highlighted in the form of elements of earth's magnetic field.

8.2. PROPERTIES OF BAR MAGNETS

It has been discovered, a long time ago, that a mineral known as *magnetite*, found in various parts of the earth, is capable of attracting iron. It is said that this mineral, which is actually an oxide of iron (ferroso ferric oxide), was first discovered in a town called Magnesia in Asia Minor ; hence the word *magnet*.

When a specimen of magnetite is dipped in iron filings the filings cling to it like whiskers, particularly in two places. When it is suspended so that it can rotate freely in a horizontal plane, it will always settle down, in a particular direction. This property of magnetite has been known for thousands of years, and the chinese, earlier than 2500 B.C. ; had used it as a primitive compass. Because of this use the name *load stone* or *leading stone* was given to the iron ore.

Any material which possesses the properties similar to those shown above is said to be a **magnet**. As the lodestone is found to occur naturally, it is called a *natural magnet*. If a lodestone is used to stroke (*i.e.* rub) a bar of iron in one direction, the iron will also acquire the same properties as those of the lodestone

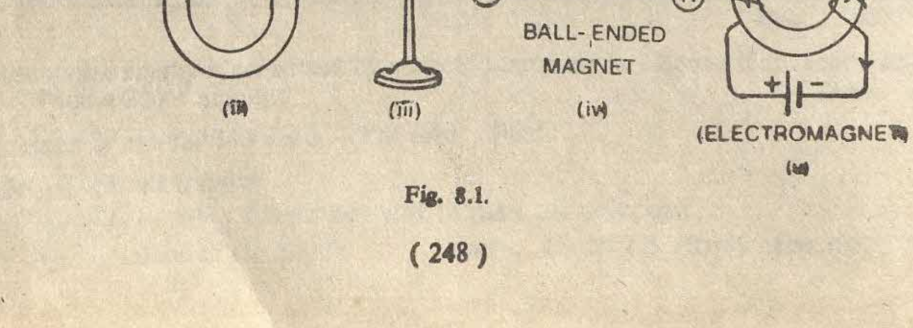


Fig. 8.1.

without the lodestone losing its magnetic power. Magnets obtained in this manner are known as *artificial magnets.*

The lodestone is now no more than a museum specimen, since artificial magnets can be quickly obtained in any shape, and they are much easier to handle than the natural magnet. Some of the artificial magnets are shown in Fig. (8.1.).

You have probably played with a magnet and been thrilled by the way it picks up small pieces of iron, such as nibs, pins and nails. However, you probably do not know that a magnet can do more than pick up pieces of iron. Now, try the following experiments and see what else a magnet can do :

Experiment. *To list those substances which can be attracted by a magnet and those which cannot.*

Requirements. A bar magnet, iron nails, pieces of steel, glass, wood, nickel, copper, aluminium, cork, cobalt, sulphur and carbon.

Procedure. Move the bar magnet near these substances and record your observations in two columns as shown below :

Substances attracted by the magnet	*Substances not attracted by the magnet*
1.	1.
2.	2.
3	3.
4.	4.
	5.
	6.
	7.

You will find that only four substances in your list are attracted by the magnet. These are iron, steel, cobalt and nickel and these four are called *magnetic substances*, while all others are called *non-magnetic substances*. Magnetic substances can be attracted by a magnet, and they can also be turned into a magnet. Non-magnetic substances have neither of these properties.

Experiment. *To find out where the power of attraction in a magnet is situated or concentrated.*

Requirements. A bar magnet, iron filings and a piece of paper.

Procedure. Spread out some iron filings over a sheet of paper. Roll the magnet, in the filings, taking care that all parts of the magnet touch the filings. Lift up the magnet and observe how the iron filings are distributed all over the magnet.

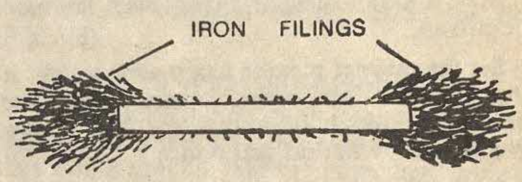


Fig. 8.2. The poles of a magnet.

You will notice that most of the iron filings cling to the two ends of the magnet while there are very few iron filings around the middle (Fig. 8.2). These two regions where the magnetic power of the magnet seems to be concentrated, *i.e.*, where the magnetic attraction is strongest, are called the *magnetic poles* of the magnet.

Experiment. *To observe what happens when a magnet is suspended freely in a horizontal position.*

Requirements. A bar magnet, copper wire, thread and wooden stand.

Procedure. First twist the wire to form a stirrup as shown in Fig. 8.3 and hang it from the wooden stand using a thread. (Can you explain why a wooden stand and a copper stirrup are used ?) Now place the bar magnet in the stirrup so that it lies horizontally. Let it move freely until it comes to rest. Note in what direction it rests. You may use a pencil line on a sheet of paper placed below the magnet to mark this direction. In this case your

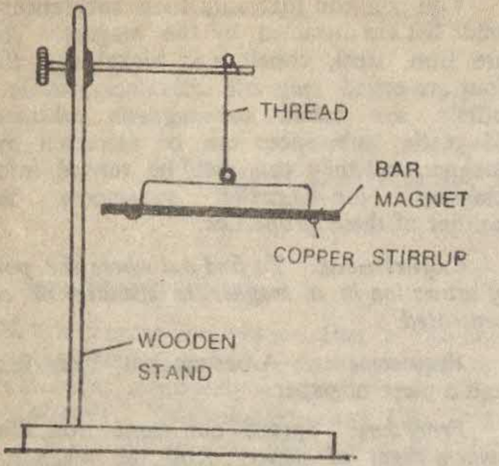


Fig. 8.3. A suspended magnet.

magnet will have to be hanging close to the sheet of paper.

N.B. A small sheet of paper may be used as a stirrup.

Set the magnet moving again and watch it come to rest once more. Again mark the direction in which it rests. Try this a few more times. What do you notice ?

You will notice that the magnet settles so that its poles lie in the same definite direction every time. This direction, you will observe, is approximately north and south. The pole that always points north is called the north-seeking pole (or *North Pole*), while the other pole is called the south-seeking pole (or *South Pole*).

Experiment. *To watch the action of a magnetic pole on another magnetic pole.*

Requirements. Two cylindrical bar magnets, wooden stand, copper or paper stirrup, thread.

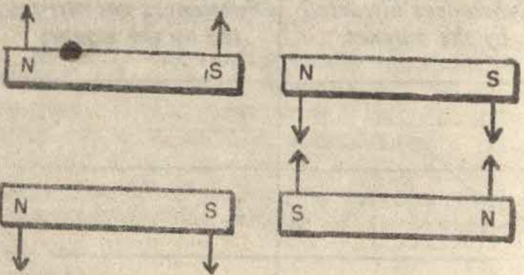
Procedure. Set up the apparatus as in the last experiment and use it to find the poles of the two bar magnets. Mark the two North Poles with chalk.

Now place one of the magnets in the stirrup. Bring near to its North Pole first the North Pole and then the South Pole of the other magnet. Note what happens in each case. Repeat the process by moving both poles of the magnet in turns to the South Pole of the suspended magnet. Again, note what happens.

Record your observations in the table shown below, using the words 'attraction' or 'repulsion'.

	Effect on North Pole of suspended magnet	*Effect on South Pole of suspended magnet*
North Pole brought near		
South Pole brought near		

Now take the suspended magnet from the stirrup and place both magnets side by side on the table, first with the North Poles in the same direction [Fig. 8.4 (*a*)] and then with the North Poles in opposite directions [Fig. 8.4 (*b*)]. Note what happens in each cash. You will notice that in the first case the magnets will roll away from each other, while in the second they roll towards each other.



(*a*) Like poles repel.
(*b*) Unlike poles attract.

Fig. 8.4. The action of magnetic poles on one another.

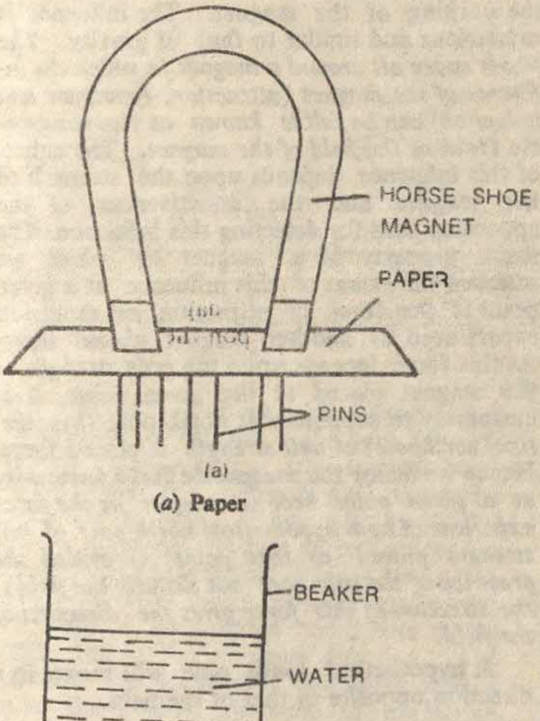
These observations added to those filled in the table above can be summed up by saying that *like poles repel and unlike poles attract,* the force of attraction or repulsion acts along the line joining the two poles and is inversely proportional to the square of the distance between them and this is the rule for forces between magnetic poles, an important rule in magnetism.

Experiment. *To show that a magnet will act through non-magnetic substances such as* *paper and glass but not through magnetic substances such as iron and steel.*

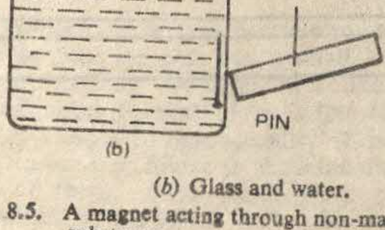
Requirements. A bar magnet, a horseshoe magnet, a sheet of paper or thin cardboard, a beaker of water, a bottle of iron filings, an iron ring, a small compass, iron pins and nails.

Procedure. (*a*) Place some iron pins or nails on the table. Cover them with a sheet of paper or thin cardboard. Now move a magnet above the paper. Let the magnet touch the paper and then lift up the magnet. What do you notice ? [See Fig. 8.5 (*a*)].

(*b*) Again, place a pin in a beaker of water. Move a magnet near so that it touches the beaker near thepin [Fig. 8.5 (*b*)]. Carefully move the magnet up the beaker and notice what happens to the pin in the water.



(*a*) Paper



(*b*) Glass and water.

Fig. 8.5. A magnet acting through non-magnetic substances.

(*c*) Move a magnet near a bottle containing iron filings and watch how the filings behave as the magnet is moved up and down.

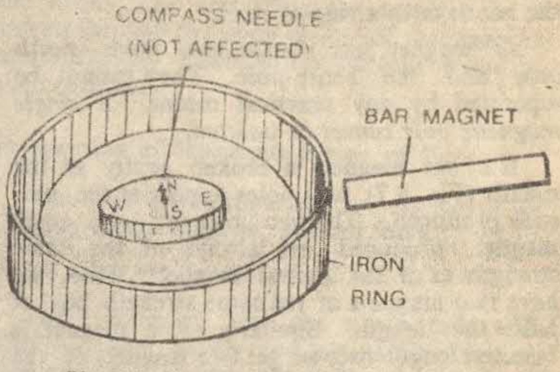


Fig. 8.6. A magnet cannot act through a magnetic substance.

(*d*) Place the small compass needle at the centre of the iron ring. Now move a magnet about outside the ring and watch the movement of the compass needle inside the ring (Fig. 8.6).

You will no doubt notice the following :

In (*a*) the paper clings to the magnet and carries with it the pins and nails [Fig. 8.5 (*a*)]. This would suggest that the paper has suddenly become a magnet attracting the pin. In actual fact, the paper is still non-magnetic, but it allows the magnet to act through it.

In (*b*) the pin moves up the beaker because it is attracted by the magnet. In this case, as in (*a*), the magnet has acted through the glass and the water, both of which are non-magnetic.

In (*c*) the iron filings seem to be dancing about in the bottle as the magnet moves up and down outside the bottle. Here again, the magnet acts on the filings through glass.

In (*d*) the compass needle in the iron ring does not move at all ; that is, the magnet outside the ring has no effect on it. Thus, a magnet does *not* act through iron, which is a magnetic substance.

From the observations outlined above it is easy to conclude that magnets act through non-magnetic substances, but not through magnetic substances. **It should be noted that the non-magnetic substance must not be too thick.**

From the above experiments you can see that if we want to protect anything from the effect of magnetism all we have to do is to surround it with a ring of iron or of any other magnetic substance. A watch, for instance, can be rendered anti-magnetic by surrounding the hands with a ring of steel.

A magnet has always two poles—north pole and the south-pole. They cannot be separated by any practical means. *A single magnetic pole cannot be isolated.*

If a bar magnet is broken gently at the middle (Fig. 8.7), new poles appear at the new ends produced. The two poles of each small magnet produced are always of the same strength as of the parent magnet. Thus, we have two magnets of the same strength but of half the length. Similarly if a magnet is bisected lengthwise, we get two magnets of the same length but of half the strength. If this process of division is carried on by the two above mentioned methods alternately, the smallest piece will be a molecule which will also be magnet in itself having northpole and south pole. Thus every magnet consists of small molecules which in themselves are small magnets and each of them has a north pole at one end and a south pole at the other. These small magnets are *magnetic dipoles.*

From the experiments outlined above, it is easy to conclude that

(*i*) A bar magnet attracts iron filings more strongly near its free ends. These ends are called the *poles.*

(*ii*) If a bar magnet is suspended in such a way that it is free to rotate in a horizontal plane, it takes the north-south direction. The end which points towards the north is called the *north-pole* and the end which points towards the south is called the *south-pole.*

(*iii*) *Like poles repel and the unlike poles attract each other.* The force of attraction or repulsion acts along the line joining the two poles, and is inversely proportional to the square of the distance between them.

(*iv*) A magnet can induce similar properties in some substances. We call these *magnetic substances.* Iron is one of the most important magnetic materials. We call this phenomenon *magnetic induction.*

(*v*) If we break a magnet into two or more smaller pieces, even the smallest possible magnet has both north and south poles. *We cannot obtain isolated magnetic poles.*

8.3. MAGNETIC FIELD

It has been seen that a magnet attracts pieces of iron or steel even when they are lying at a certain distance away from it. A compass needle also placed at such a point is influenced by the magnet, although nothing happens in the space between the magnet and the needle. A screen of wood, glass or and other non-magnetic material will not obstruct the working of the magnet. The influence is mysterious and similar to that of gravity. *The whole space all around a magnet in which the influence of the magnet (attraction, repulsion and induction) can be felt is known as* **the magnetic field** *or the field of the magnet.* The extent of this influence depends upon the strength of the magnet and the sensitiveness of the apparatus used for detecting this influence. The main property of a magnet by which we measure the extent of this influence at a given point is the force of attraction or repulsion experienced by another magnet placed there. As this force depends upon the pole strength of the magnet placed at the given point, it is customary to suppose that north-pole (*hypothetical northpole*) of *unit strength* is placed there. Hence we define the **magnetic field intensity** *at a given point near a magnet as the force experienced by a hypothetical north pole of unit strength placed at that point (provided the presence of the pole does not disturb the field); the direction af this force gives the direction of the field.*

A hypothetical south pole will move in a direction opposite to that of the field.

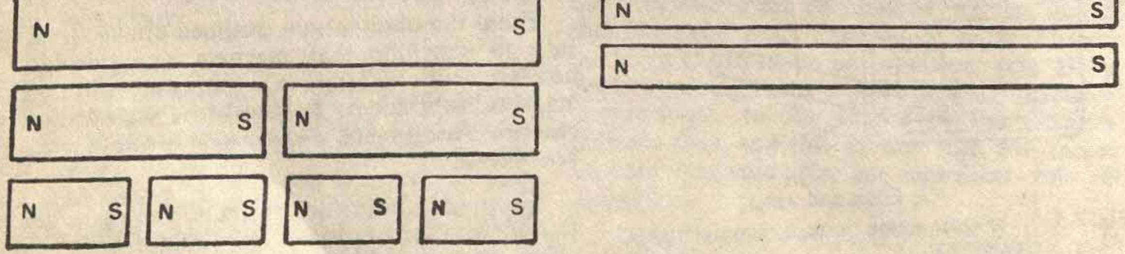


Fig. 8.7.

8.4. MAGNETIC LINES OF FORCE

Let us consider a point P in the field of the bar magnet NS (Fig. 8.8). Suppose a free and isolated north pole to be placed at this point. There are two forces acting on this isolated pole (*i*) a force of repulsion due to N—pole and acting along NP and (*ii*) a force of attraction due to S—pole and acting along PS. The resultant of these two forces will act along, say, PP'. If the free, isolated pole is now placed at R, there will again be two forces acting on it. These two forces differ in magnitude as well as in the direction from those acting at P and therefore their resultant will be acting in different direction, say RR'. Thus if a free and isolated north pole is placed in the field of a magnet, it will be moving along a curved path starting from the N—pole and terminating at the S—pole of the magnet. *The path* (straight or curved) *along which a free isolated north pole would travel in a magnetic field* is called a *magnetic line of force*. It may also be defined as *a curve, a tangent to which at any point gives the direction of the resultant field at that point.* Generally we refer to an isolated north pole, but the path of an isolated south pole would be similar but in the opposite direction. The direction of the movement of a north pole is taken as the positive direction of the line of force.

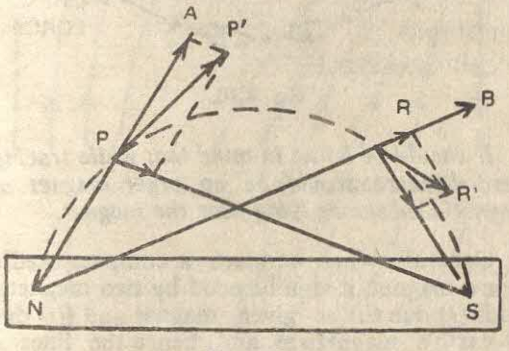


Fig. 8.8.

In practice it is not possible to obtain a single pole but we can use a small compass needle for tracing the lines of forces. This needle will come to rest along a line of force. Instead of using a compass needle, it is much simpler to use iron filings to show the direction of lines of force. Each small piece of iron is magnetised by induction and behaves like a small magnet.

From each point of the north pole, one line of force starts and passing through space it terminates on a corresponding fixed point on the south pole and from the south pole it travels through the body of the of the magnet and ultimately returns to the starting point on the north pole.

Properties of Magnetic Lines of Force

The following properties are attributed by Faraday to the magnetic lines of force :

(*i*) They are closed curves.

(*ii*) They start from the north pole and after travelling in air end on south pole and then continue through the body of the magnet to the north pole again. Inside the magnet they are known as *lines of induction.*

(*iii*) They never intersect one another as, at one point (the point of intersection) there cannot be two directions of the resultant magnetic field.

(*iv*) They behave like stretched, elastic threads and tend to decrease in length (Longitudinal contraction). They repel each other sideways (Lateral repulsion).

(*v*) They start from a surface normally and also end at the surface normally.

(*vi*) The lines of force are connected at the poles ; thus the number of these lines of force per unit area is a measure of the field intensity at a point in that area. When lines of force come closer together, it indicates a stronger magnetic field and vice-versa.

(*vii*) There are no lines of force inside an iron ring as they tend to pass through iron rather than through air.

While the magnetic lines of force may seem to the beginners to be quite imaginary, we shall find later on that they are very useful in explaining the various electrical and magnetic phenomena.

Lines of force have no real existence, they are merely graphical representation of the magnitude and direction of magnetic force at any point in the field These properties attributed to the lines of force can be utilized to explain ordinary phenomena like Induction, Attraction and Repulsion.

8.5. MAPPING THE MAGNETIC FIELDS

Exhibiting the magnetic lines of force in a magnetic field is known as mapping of the field. There are two ways of mapping this field (*i*) by means of iron filings, (*ii*) by means of a small compass needle.

(*i*) **By Iron Filings.** The iron filings method of mapping lines of force is a device by which we show the direction of the field, just as a chain hanging vertically indicated the direction in which the force of gravity acts.

Place a thin glass sheet over a magnet and sprinkle small iron filings over it. On gently tapping the sheet it is found that iron filings arrange themselves in beautiful curves. These curves represent lines of force in the plane of the glass sheet. The iron filings arrange themselves in chains because each individual filing becomes a small magnet by the induction effect and arranges itself along a definite direction under the influence of the two poles of the magnet. Fig. 8.9 shows the lines of force between two dissimilar poles of two magnets.

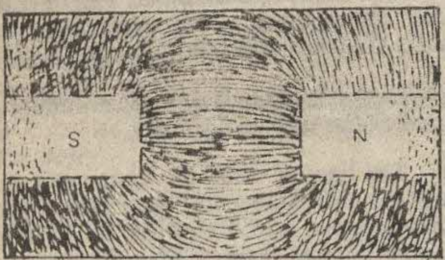


Fig. 8.9.

(*ii*) **By means of a Compass Needle.** This method is much more sensitive and accurate than the previous method. A compass needle which consists of a very short and thin magnetised steel strip pivoted as its centre of gravity and enclosed in a glass casing is placed near one end (pole) of a bar magnet placed on a paper fixed on a wooden board. The two poles of the magnet exert forces an this needle and take up the direction of the resultant of these forces (Fig. 8.10). Two pencil marks are then made near the two ends of the needle. The compass is then moved towards the second pole so that the end of the needle which was close to the first point now lies over the second point *i.e.* the south pole occupies the position previously occupied by its north pole and mark the new position indicated by the north pole. Another mark is then made near the second end. This gives us the third point of the series. This process is continued till we reach the other pole (Fig. 8.10). A smooth curve passing through all these points gives us a magnetic line of force. By starting from different points we can out the whole of the field.

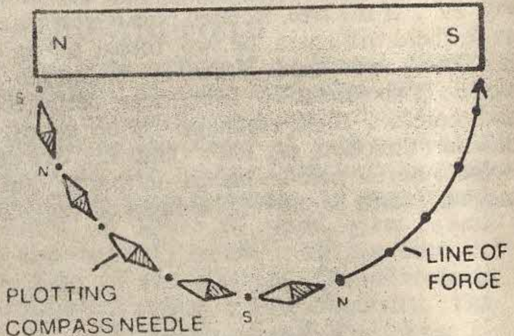


Fig. 8.10.

It should be borne in mind that while tracing this field there should be no other magnet or magnetic substance lying near the magnet.

Generally when we place a compass needle near a magnet, it is influenced by two magnetic fields (*i*) due to the given magnet and (*ii*) due to earth's magnetism and hence the lines of force are due to the combined effect of the two fields. The field due to earth's magnetism is fairly uniform but that due to the magnet goes on decreasing as we go away from the magnet. At points very near the magnet, the lines of force are mainly due to the influence of the magnet due to earth's magnetism is comparatively very weak. But at points at a certain distance away from the magnet, the lines of force are predominantly due to earth's magnetic field. At point in between these two limits we have points in certain directions where the two fields are equal and opposite and thus cancel each other completely. *Such points are known as* **Neutral Points.** *There is no resultant magnetic field at these points. A compass needle kept at such a point will experience no resultant force and will point in any direction.*

If the magnet is positioned so that its north pole is pointing in the direction of the magnetic north pole of the earth then the pattern in (Fig 8.11) results. If the magnet is now placed with the north seeking pole pointing to the magnetic south pole of the earth, the pattern

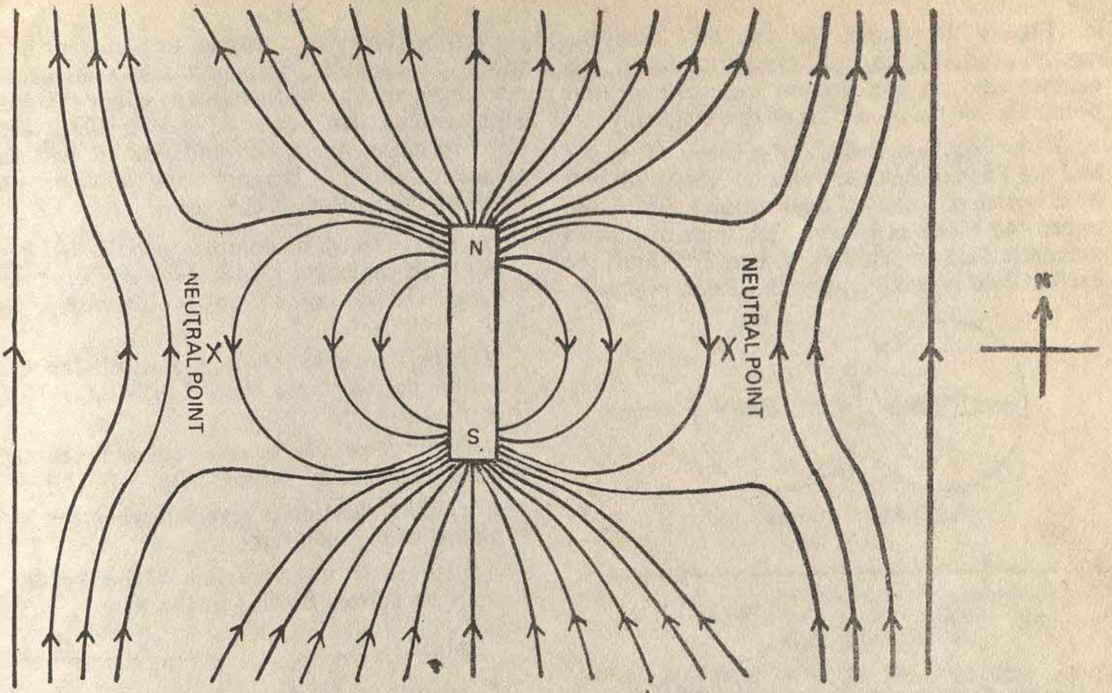


Fig. 8.11. Magnetic field round a bar magnet with its north pole pointing towards north.

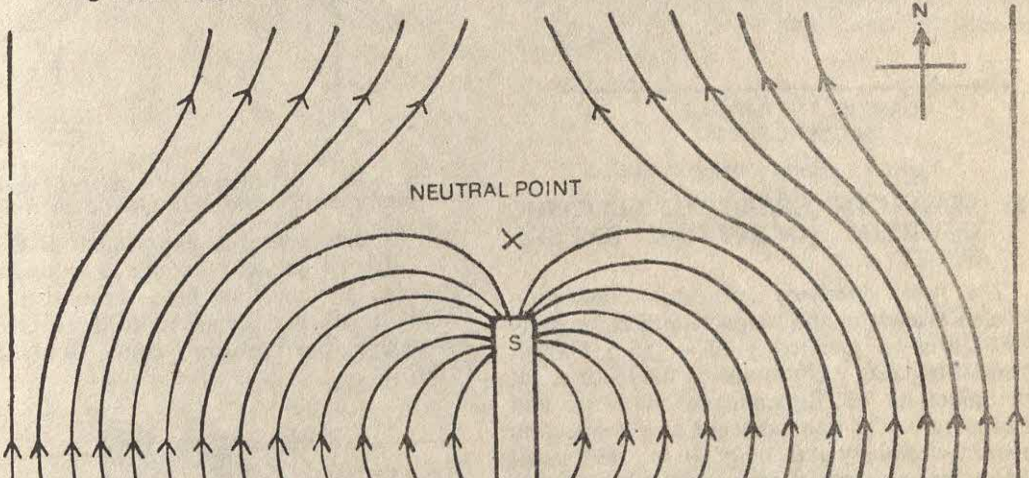


Fig. 8.12. Magnetic field round a bar magnet with its south pole pointing north.

in (Fig. 8.12) results. In the first case the neutral points lie on the *equatorial line* of the magnet and in the second case the neutral points lie on the *axial line* of the magnet.

If the compass is laid on a sheet of paper and the lines of force are plotted, the result will be a series of *parallel lines* running across the paper and these represent the lines of Earth's magnetic field as shown in Fig. 8.13 and the earth's field is *uniform* over this *small region*.

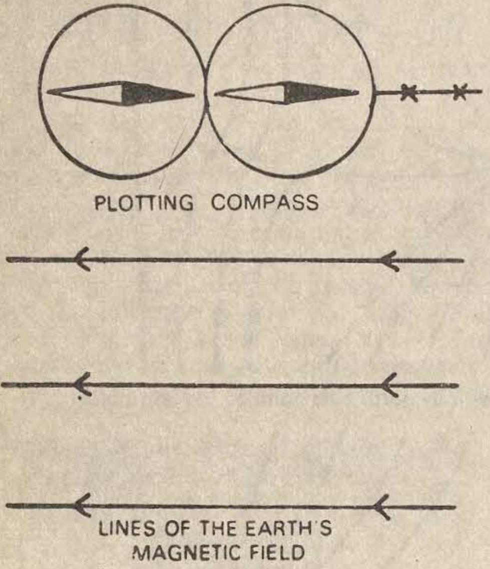


Fig. 8.13. Earth's magnetic field.

8.6. MAGNETIC EFFECT OF ELECTRIC CURRENT (OERSTED'S EXPERIMENT).

The first discovery of any connection between electricity and magnetism was made by Hans Christian Oersted (1777—1851), Danish Scientist in 1820. Often during his lectures, at the university of Copenhagen. Oersted had demonstrated the non-existence of a connection between electricity and magnetism. His usual custom was to place a current-carrying wire at right angles to and directly over compass needle show that there was no effect of one on the other. On one occasion at the end of his lecture, when several of the audience came up to meet him at the lecture room desk, he placed the wire parallel to the compass needle and not the least expecting it, saw the needle move to one side. Thus this great discovery was made quite by accident, but, such accidents come only to those who deserve them. Thus magnets are not the only sources of magnetic fields. Oersted discovered that a wire carrying current behaves like a magnet or a current in a wire was capable of generating a magnetic field. We now know from many other types of experiments that this is indeed the case. Further, more, there are indications that the magnetic field of a magnet may also be the result of the motion of charges.

Oersted placed a compass needle *NS* Fig. 8.14 on the table and held a wire *PQ* over this needle. On passing current in the wire found that

(*i*) the *N*-pole is deflected towards the west when the current flows from *S* to *N i.e. P* to *Q* [Fig. 8.14 (*a*)].

(*ii*) the *N*-pole is deflected towards the east when the current is reversed [Fig. 8.14 (*b*)].

(*iii*) the deflection is reversed when the wire is placed *below* the needle.

(*iv*) there is no deflection of the needle if there is no current flowing in the wire.

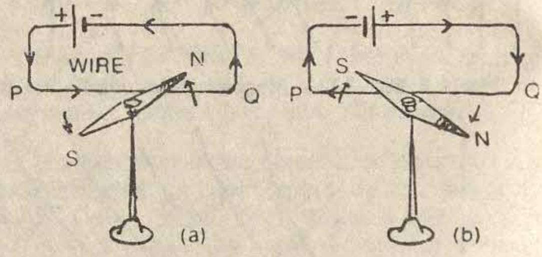


Fig. 8.14. The deflection of a magnetic needle under the influence of an electric current.

It follows from this experiment that whenever current is passed through a conductor, it produces a magnetic field around it. The direction of this magnetic field is given by **Ampere's Swimming Man Rule** stated below :

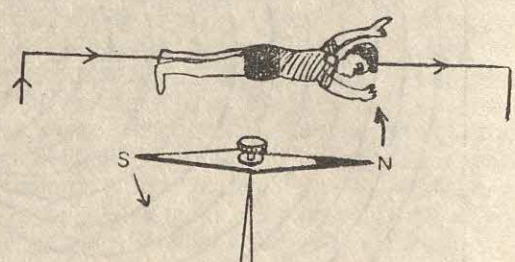


Fig. 8.15. Swimming rule.

"Suppose yourself to be swimming along the conductor carrying current, so that the current enters at your feet (Fig. 8.15) and leaves at your head and you are looking at the needle, the north pole of the needle will be deflected towards your left."

Ampere's rule may be remembered by the word **SNOW** which means that if the currents flow from South to North and the wire is Over the needle, the north pole is deflected towards West.

8.7. MAGNETIC FIELD DUE TO A STRAIGHT CONDUCTOR (ARAGO'S EXPERIMENT)

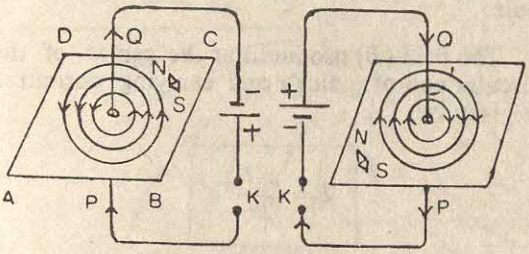


Fig 8.16. The direction of the magnetic field round a straight conductor carrying current.

Arago took a card-board piece *ABCD* and fixed it horizontally and passed a thick copper wire *PQ* vertically through the board (Fig. 8.16). A strong electric current was passed through this wire following from *P* to *Q* [Fig. 8.16(*a*)] and iron fillings were sprinkled on the card board and the card-board was then gently tapped. The fillings arranged themselves in concentric circles with their common centre at *O* where the wire passes through the card-board. These iron fillings arrange themselves along the magnetic lines of force round the conductor. The *N*-pole of a magnetic needle placed any where near the conductor tends to move in the anticlockwise direction.

If, however, the direction of the current is reversed [Fig. 8.16(*b*], the north pole begins to point in the clockwise direction.

Right Hand Rule

Arago's experiment also clearly shows that an electric current is always associated with a magnetic field. The direction of this field is given by **Right Hand Rule** stated below :

"Hold the thumb of your right-hand at right angles to the fingers. Grasp the wire carrying current in the right hand so that the thumb points along the wire in the direction of the current ; the fingers will then point in the direction of the magnetic field *i.e.*, in the direction in which the north pole will be deflected." (Fig. 8.17).

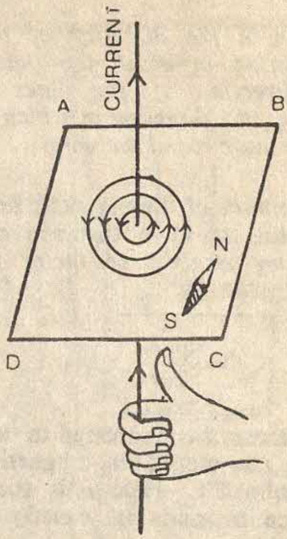


Fig. 8.17. Right hand rule for determing the direction of the field round a conductor carrying current.

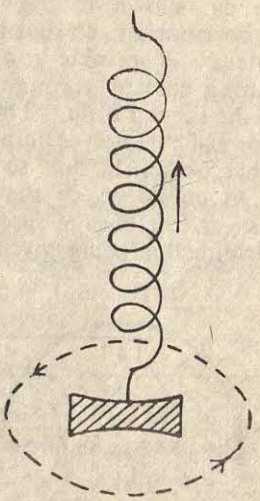


Fig. 8.8. Cork screw Rule.

The direction of the field around a conductor can also be determined with the help of the **Cork-Screw rule** in the following way.

"Imagine an ordinary right hand cork screw to be lying with its direction coinciding with the conductor carrying current and to be twisted so

that it travels in the direction of the current, then the direction in which the thumb rotates gives the direction of the lines of force (Fig. 8.18) i.e., the direction in which the north pole tends to move round the wire.

The *magnitude* of the magnetic field $\vec{B}$ produced in vacuum at a distance r from an *infinitely long straight conductor* carrying a current I is given by

$$\boxed{B=\frac{\mu_0 I}{2\pi r}}$$

when the current I is expressed in ampere and the distance r in metre, the magnetic field B is in *tesla* (symbol T). Here μ_0 is the permeability of vacuum and is exactly equal to $4\pi\times10^{-7}$ Tm/A.

8.8. FIELD PATTERN DUE TO A CIRCULAR-COIL CARRYING CURRENT

Take a sheet of carboard $ABCD$ and make two holes (P and Q) in it a little apart from each other. Pass a thick stout copper wire through these holes bent in the forms of a circular loop as shown in Fig. 8.19. Hold the carboard horizontally, so that the coil is in the vertical plane and sprinkle iron fillings upon it. Pass a strong current through the copper wire and tap the sheet a little. The iron fillings are seen to adjust themselves along the directions of the magnetic field due to the current in the coil. At points where the wire passes through the sheet, the lines of force are almost circular, their direction being given by the *right hand rule*.

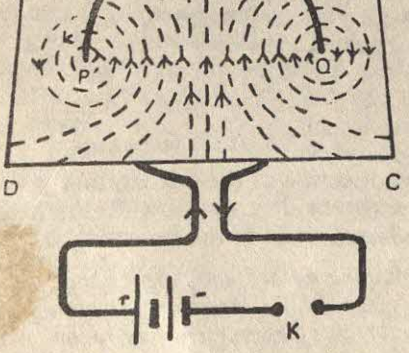


Fig. 8.19. The magnetic field round a circular coil of wire

It will be noted that the field at the centre of the circular coil is always from the observer and perpendicular to the plane of the coil. The lines of force at the *centre* are parctically straight showing that the magnetic field due to the current in the coil is *parctically uniform*. If the current is reversed *i.e.*, anticlockwise, the field will be towards the observer.

With the help of **clock rule** the polarity of any face of the coil can be determined. If the current round any face of the coil flows in an anti-clockwise direction, it behaves like a north pole. Similarly, if the current flows in the clockwise direction, the face acts like a south pole.

The field (B) produced at the centre of the circular coil of radius r and carrying current I is given by

$$\boxed{B=\frac{\mu_0 I}{2r}}$$

If there are n turns of the coil then,

$$B=\frac{n\mu_0 I}{2r}$$

8.9. MAGNETIC FIELD DUE TO A SOLENOID

A long coil of wire is called a solenoid. The magnetic field due to current flowing in a Solenoid is shown in Fig. 8.20.

It is even more obvious here that the field is identical with that of a bar magnet. Such a solenoid (when a current is flowing through it), if suspended freely, will set itself along N and S like a compass needle. The ends of the current-bearing solenoid are attracted or repelled by a bar magnet.

An important difference between a current bearing solenoid and a bar magnet is that the solenoid is hollow and has an intense magnetic field along its axis, while a magnet is solid. It should be noted that in Fig. 8.20 the lines of force inside the solenoid run for the end of south polarity to the end of north polarity. The positive direction of the magnetic field inside a solenoid is from the south end of the north end.

Students Activity :

Arrange the device as shown in Fig. 8.21.

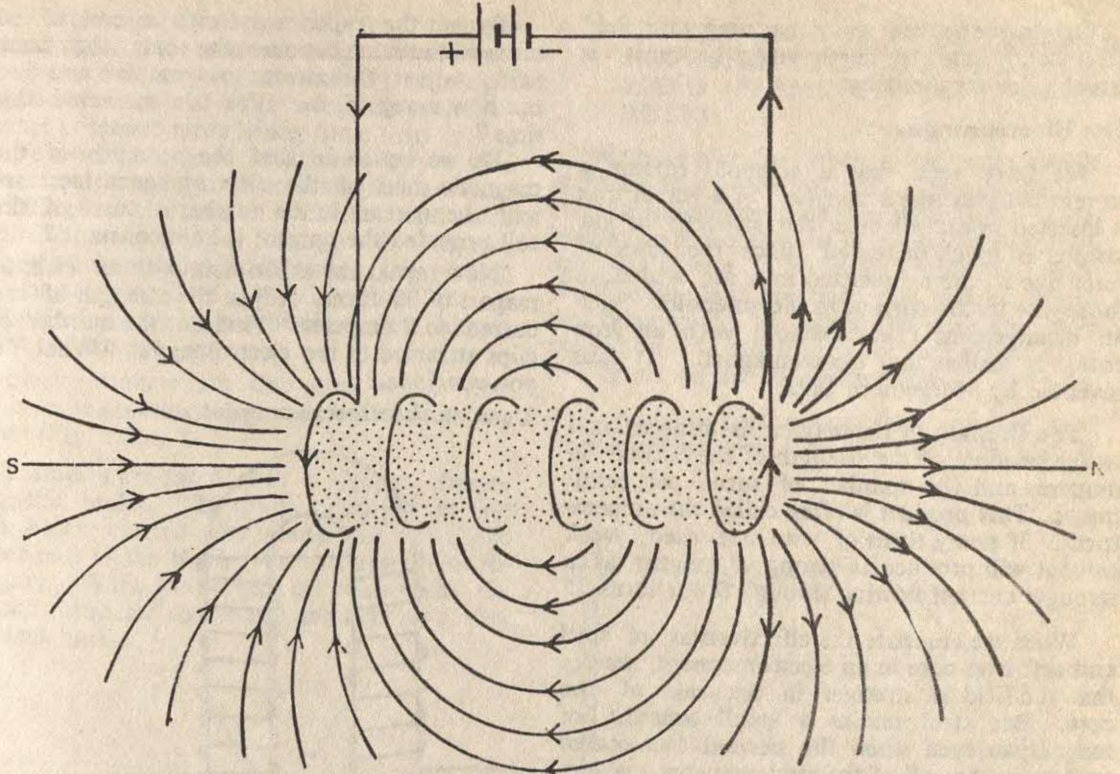


Fig. 8 20. Field due to a Solenoid.

Here the turns of the solenoid are passed through the top of the cardboard table.

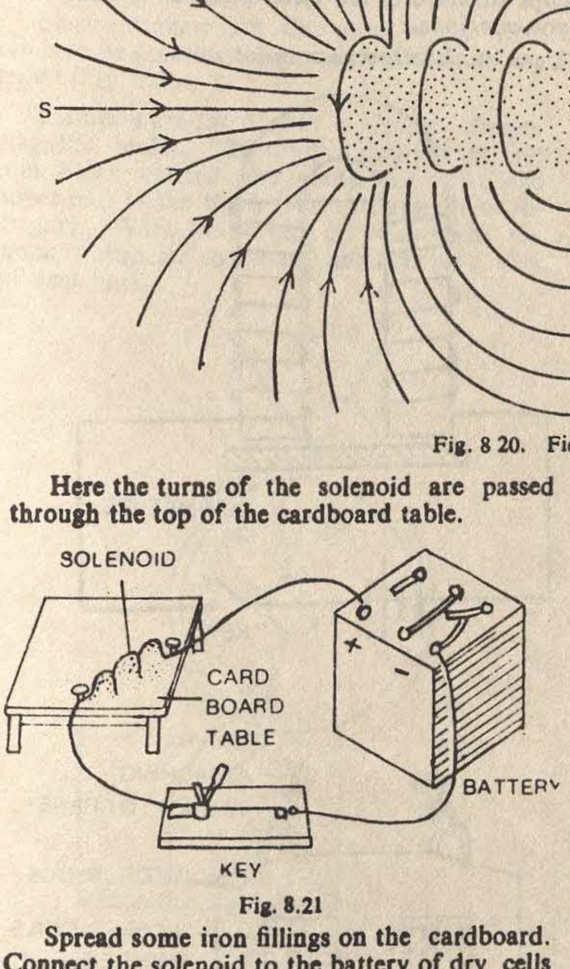


Fig. 8.21

Spread some iron fillings on the cardboard. Connect the solenoid to the battery of dry cells and tap the table gently. What do you observe? How do the iron fillings arrange inside the solenoid ? What does the distribution of magnetic lines of force demonstrate ?

Determine the poles of the coil with the help of a magnetized needle. From which pole do the magnetic lines of force emerge ?

Magnetizing Action of a Solenoid

If a bar of iron is placed inside a solenoid carrying a strong current it becomes magnetized. The end of the bar at the end of north polarity of the solenoid acquires a North pole and the other end a South pole. This is a much quicker and more effective method of magnetizing than stroking with a bar magnet. The direction of magnetization clearly depends on the direction of the current and the way the solenoid is wound (Fig. 8.22).

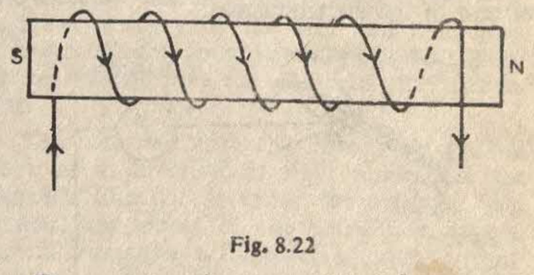


Fig. 8.22

To sum up the properties of a current-carrying solenoid.

(*i*) Outside it resembles a bar magnet.

(*ii*) Inside it has a strong magnetic field from south end to north end ; hence it is valuable for magnetizing.

The Electromagnet :

We have seen that a solenoid carring a current behaves like a magnet. If a bar of iron is inserted in the solenoid, the strength of the magnet is much increased, since the lines of force due to the magnetized iron are added to those due to the current in the solenoid. Such an arrangement (*i.e.*, solenoid with an iron core) is called an electromagnet. It was invented by Sturgeon in 1825.

The strength of the magnet is proportional to the product of the strength of the current in amperes and the number of turns per centimeter. This product is often called the ampere-turns. If many turns of wire are used, weak current will produce as strong a magnet as a stronger current flowing through fewer turns.

When we compare the effectiveness of steel and soft iron core in an electromagnent, we see that the field is stronger in the case of iron core. But steel retains a small amount of magnetism even when the current has ceased to flow in the coil of the electromagnet, whereas in the case of soft iron core the magnetism disappears altogether as soon as the current ceases to flow in the coil of the electromagnet.

Make a coil of 30 turns of an insulated copper wire around a large iron nail. This will be our electromagnet. Connect the ends of the electromagnet to a storage battery through an ammeter and a rheostat as shown in Fig. 8.23. Bring some paper clips near one end of the electromagnet. Switch on the current and adjust it to a strength of 1 amphere with the help of the rheostat. What do you observe ? Count the number of paper clips attracted to the end of the electromagnet.

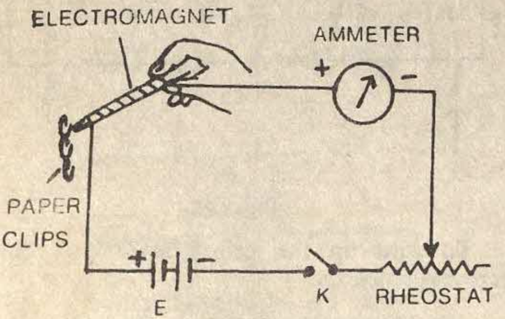


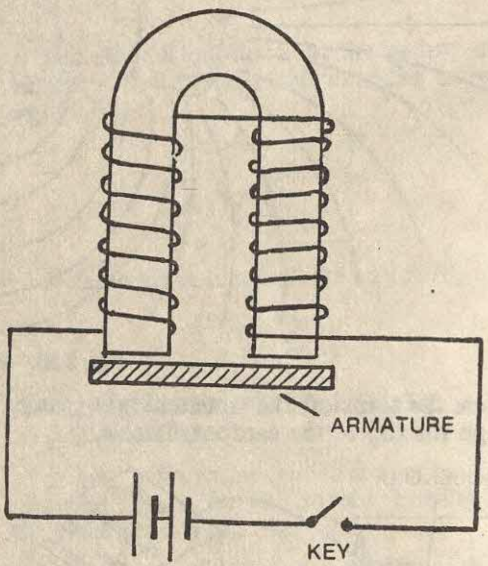
Fig. 8.23

Repeat the experiment with a coil of 60 turns of the same copper wire over the same nail. Adjust the current to 1 ampere and find out how many of the clips are attracted this time ?

Do we conclude that the strength of the magnetic field of the electromagnet increases with the increase in the number of turns of the coil provided the current is kept constant ?

Now repeat the experiment with an electromagnet of 30 turns. Adjust the strength of the current to 2 amperes. Find out the number of clips attracted to the electromagnet. What do you conclude ?

Uses of the electromagnet



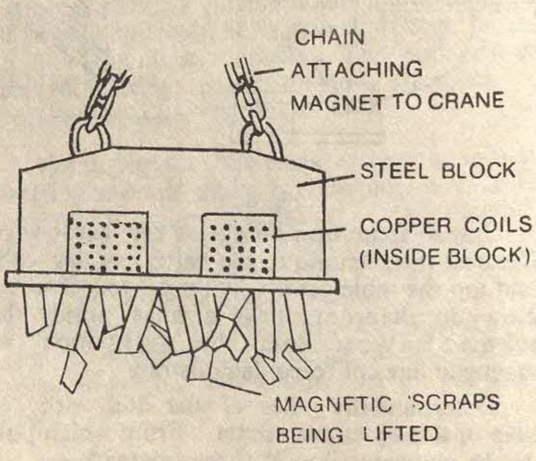


Fig. 8.24

Electromagnets have different shapes depending on their purpose Fig. 8.24 shows a horse-shoe electromagnet holding a weight suspended from it. The horse-shoe electromagnet possesses more lifting force than a bar electromagnet because it attracts by its two poles simultaneously. Electromagnets are used for lifting heavy masses of iron and steel such as girders, scrap iron, or a cargo of nails, for separating iron and copper scraps for picking out tins and iron from a city's refuse, and in hospitals, for drawing out pieces of iron lodged in the human eye.

Electromagnets are also used when iron ore is to be separated from rocks in iron ore mines (Fig. 8.25).

Tramcars are fitted with a slipper electromagnetic brake. The slipper consists of an iron block carried just above the rail; the upper part of the block is wound as an electromagnet. When the current is switched on, the block is attracted to the rail and acts as a very efficient brake.

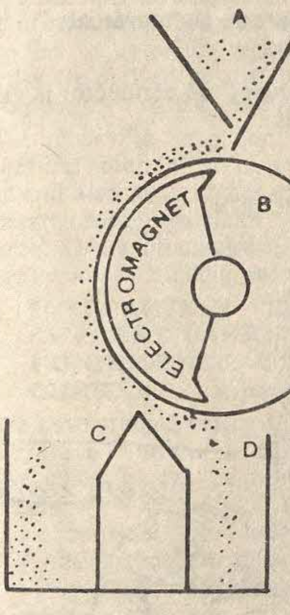


Fig. 8.25

Lamps are made with an electromagnet in the base which clings to iron when the lamp is switched on.

Other most useful applications of electromagnets are :

(*i*) The electric bell (*ii*) Electric Telegraph (*iii*) Telephone (*iv*) Dynamos or generators (*v*) Electric motor (*vi*) Microphone, etc.

8.10. FORCE ON A CURRENT-CARRYING CONDUCTOR IN A MAGNETIC FIELD (FLEMING'S LEFT HAND RULE)

We have seen that when a magnetic needle is placed near a wire carrying a steady electric current, the magnetic needle experiences forces tending to move its poles in directions perpendicular to the wire. In accordance with the principle of action and reaction, one would expect that there would be equal and opposite forces exerted on the wire carrying the current. For this, let us do the following activity.

Loosely support a long thick copper wire from a copper wire loop (Fig. 8.26) so that it hangs vertically between the poles of a horse-shoe magnet, with its lower end just dipping into mercury held in a small metal cup. Connect the mercury in the cup and the copper loop through a tapping key to a dry cell. Close the key and observe the action on the conductor.

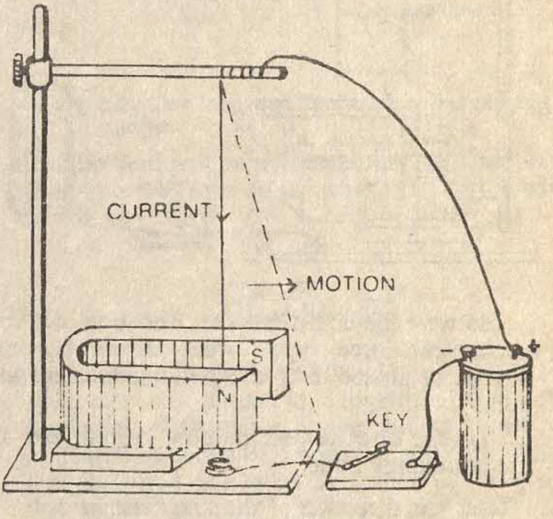


Fig. 8.26.

You will see that the wire is observed to move in a direction at right angles to the magnetic lines of force of the magnetic field between the poles of the horse-shoe magnet. This indicates that a force acts upon a current-bearing conductor placed in a magnetic field. Now change the direction of the current flow in the conductor and observe the effect in the conductor. This time the copper wire is found to move in the opposite direction.

Now turn the horse-shoe magnet by 180° keeping the copper wire in-between the poles of the magnet *i.e.* interchange the positions of North and South poles of the magnet and thereby change the direction of the lines of force of the magnetic field. Now switch on the current in the copper wire and observe the effect on it. You will find it to be deflected in in a direction opposite to the previous one (Fig. 8.27).

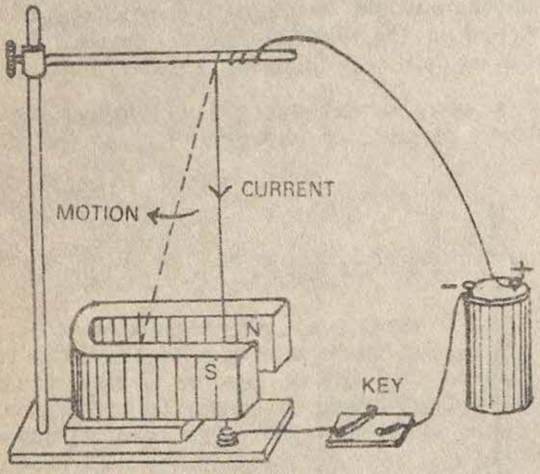


Fig. 8.27

So we conclude that the direction of the mechanical force upon the current-bearing conductor placed in a magnetic field depends upon :

(*i*) the direction of the flow of current in the conductor ; and

(*ii*) the direction of the magnetic field,

From experiments it has been found that the direction of this mechanical force is perpendicular to both, the direction of the magnetic field and the direction of the current in the conductor.

The magnitude of the mechanical force (F) experienced by the wire proportional to the current (I) it carries and also the length (l) of the wire that is in the magnetic field *i e.*

$$F \propto I\,l$$

or

$$\boxed{F = B.I\,l}$$

where $\vec{B}$ is a constant of proportionally and is known as the *magnetic field*. It is a *vector* quantity.

In the SI units, F is measured in newton, I in ampere and l in metre. Thus $B=\frac{F}{I.l}$ is measured in *newton per ampere-metre*. This unit, newton per ampere-metre, is called **tesla** (T). A smaller unit to measure magnetic field is *gauss* because tesla is a fairly big unit.

$$\boxed{1 \text{ gauss} = 10^{-4} \text{ tesla}}$$

Magnetic field of the earth near the surface is about 0·3 gauss.

Fleming's Left Hand Rule is a convenient rule for helping to remember which way the current-carrying conductor in a magnetic field would move.

The thumb, and first finger and middle finger of the *left* hand are held mutually at right angles to each other (Fig. 8.28). Then the direction of

(*a*) the *Field* is represented by the *first* finger.

(*b*) the *Current* is represented by the *middle*-finger, and

(*c*) the *Motion* of the conductor is represented by the *thumb*.

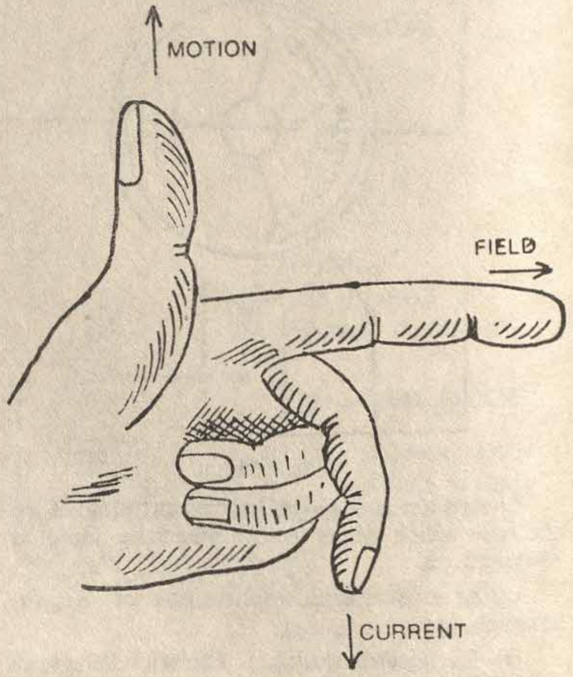


Fig. 8.28

Earlier we have studied that an electric current is just a flow of charges. Thus, moving charges in free space, like currents in a wire, also experience force in a magnetic field. The direction of the force on a moving positive charge is exactly the same as that of a current and is given by Flemings left-hand rule. In the case of a moving negatively charged particle the direction of the force is opposite to that on similarly moving positive charge. On account of this force, if a moving charged particle enters a magnetic field which is perpendicular to its motion, it experiences a force perpendicular to both, its velocity and the field. Hence it is deflected from its straight line path. If the field is uniform and the particles move in a plane normal to it, *then they will move in a circle*; the radius of the circle being larger for higher energies. Charged particles can thus get *trapped* inside a magnetic field.

One of the exciting discoveries related to the deflection of charged particles by a magnetic field was the so called *Van Allen radiation belt*. This discovery was made possible by using unmanned satellites. This belt is a Vast Zone of trapped charges encircling the earth above the equatorial regions. The charged particles are derived mostly from the sun and are trapped by the magnetic field of the earth.

The effect of a magnetic field on moving charges has been used in television, oscilloscopes and also in machines which are used to accelerate charged particles used for scientific research. One such machine, called a variable energy *cyclotron* is being put up in Calcutta.

8.11. INTERACTION BETWEEN TWO CURRENT CARRYING STRAIGHT CONDUCTORS—UNIT OF CURRENT—ampere

We have studied earlier that a wire of length L carrying a current I experiences a force $F=BIL$ when placed perpendicular to a magnetic field B.

If we consider two long parallel straight wires P and Q through which the same current I flows [Fig. 8.29 (*a*)], the wires will experience forces because each is in the magnetic field of the other. When the separation of the wires is r, the magnetic field (B) experienced by the wire Q because of the current I in the wire P, is merely

$$\boxed{B=\frac{\mu_0 I}{2\pi r}} \quad \text{where } \mu_0=4\pi\times10^{-7}\ TmA^{-1}$$

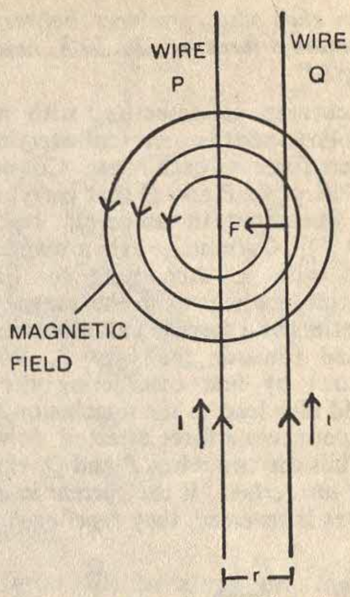


Fig. 8.29 Two long, parallel straight wires carrying current

The field will be perpendicular to the wire Q and so the force on a length L of the wire Q will be

$$F=BIL$$

or

$$\frac{F}{L}=BI=\frac{\mu_0 I^2}{2\pi r}$$

Since the force on unit length of the wire, F/L, can be measured, together with the separation of the wires, r, the current I can be evaluated in terms of known quantities. When F is measured in *newton* and when μ_0 is given the value $4\pi\times10^{-7}$ newton$-$sec^2/coul^2 (or TmA^{-1}), the current is in the unit we define to to be the *ampere*. Hence the ampere is defined directly in terms of force and length, both fundamental units.

When $I=1$ ampere ; $L=1$ metre

and $r=1$ metre

then

$$F=\frac{4\pi\times10^{-7}\times(1)^2}{2\pi\times1}=2\times10^{-7}\text{ newton}$$

This is the basis of the definition of ampere in *SI* system.

***"The ampere** is the strength of that steady current which when flowing in two parallel infinitely long conductors of negligible cross section placed in vacuum at a distance of one* *metre from each other, produces between those two conductors a force of 2×10^{-7} newton per metre length.*"

Since currents are associated with magnetic fields, it follows that two current-carrying wires should exert force on each other. Consider two long parallel wires P and Q that carry currents I_1 and I_2 (measured in ampere), respectively [Fig. 8.29 (*b*)]. Current I_1 has a magnetic field associated with it. According to Fleming's left-hand rule, the wire Q in the magnetic field of P, experiences a force(F) all along its length (L) directed towards the wire P. We could equally start by first considering the wire Q. This would also lead to the conclusion that the wire P experiences a force directed toward the wire Q. Thus the two wires P and Q, experience a *force of attraction*. If the current in any one of the wires is reversed, they *repel each other*.

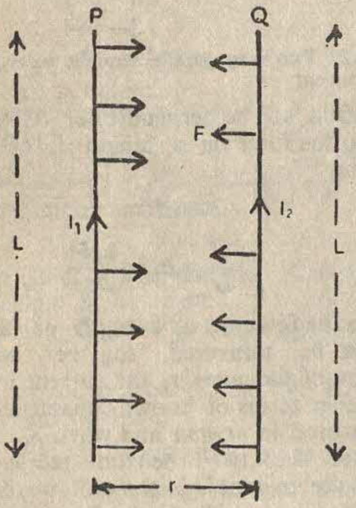


Fig. 8.29 (b) Attraction

We thus note that *two parallel wires having currents in the same direction attract each other, where as two parllel wires having currents in opposite directions repel each other.*

If r is the distance between the two wires P and Q, the magnetic field of wire P at wire Q is

$$B_p=\frac{\mu_0 I_1}{2\pi r}$$

Hence the force experienced by a lengt of Q is

$$\boxed{F=\frac{\mu_0\ I_1I_2.\ L}{2\pi\ r}}$$

8.12. GALVANOMETER.

The existence of an electric current in a conductor can be depicted by its magnetic effect. Instruments in which magnetic effect is used for measuring the current by the interaction of a magnet and a coil, through which the current passes, are known as *galvanometers*.

There are two types of galvanometers ; (*i*) the *moving magnet galvanometer* in which the coil is fixed and the magnet moves and (*ii*) the *moving coil galvanometer* in which the magnet is fixed and the coil moves. The moving magnet galvanometer is neither very suitable nor sufficiently sensitive for common use in the laboratory. What we commonly use in the laboratory and in our daily life is the moving coil galvanometer. Its design was invented by *D'* Arsonval and therefore, it is sometimes named as *D'* Arsonval Type Galvanometer.

A simple type of a moving coil galvanometer is shown in Fig. 8.30. It consists of a coil *ABCD* of a number of turns of fine insulated wire wound on a rectangular metal frame. It is suspended by a phosphor-bronze (an alloy of brass and phosphorus) strip attached to the torsion head at the top and lies between the concave poles of a strong cobalt-steel horse-shoe magnet. The suspending strip is a good conductor of electricity and thus leads the the current into the coil. At the lower end, the coil is attached to a spring of phosphor-bronze and thus the coil is firmly kept in position, such that the plane of the coil is parallel to the magnetic lines of the force of the horse shoe magnent. A cylindrical piece of soft-iron is fixed at the centre of the coil. As magnetic lines of force prefer to travel in iron rather than in air, the core helps to concentrate the lines of force into the coil or produce a strong magnetic field round it. A mirror (N) is attached at the lower end of the phosphor-bronze suspension strip to provide for the mirror and scale or the lamp and scale device of making the instrument very sensitive. The ends of the coil are connected to terminals T_1 and T_2. The magnent and the coil along with the suspension strip and the spring are enclosed in a box with a glass plate as its front face.

Since the soft core helps to concentrate the magnetic field so that the directions of the magnetic lines of force in a small air gap between the pole pieces and the core almost coincide with the radii of the cylindrical pole

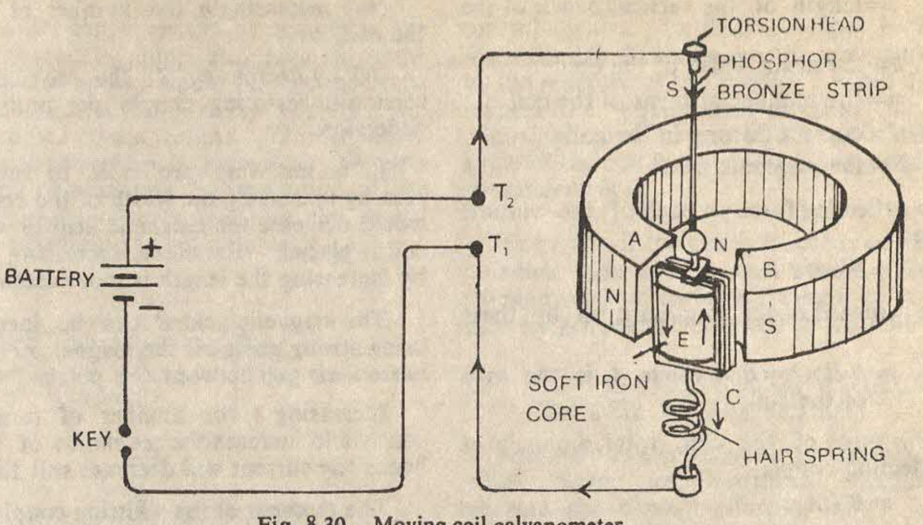


Fig 8.30. Moving coil galvanometer.

pieces (Fig 8.31). Such a field is called a **radial field**. In such a field. the plane of the coil in all its positions is always parallel to the magnetic field.

The *principle* on which a moving coil galvanometer works is based on the fact that when a conductor carrying current is placed in a magnetic field, it experiences a force perpendicular to both, the current and the field and hence is pushed in a direction given by *Fleming's Left Hand Rule.*

If the current flows downwards through the left-hand branch *AE* of the coil, by Fleming's Left Hand Rule, this part of the coil would come out of the paper and the right hand side limb *CB* will go into the paper (Fig. 8.32). As these two forces acting on the limbs are parallel, equal and opposite in direction, they constitute a couple which would tend to rotate the coil. It is called the *deflecting couple.* As the deflecting couple rotates the coil, an elastic force due to twisting of the suspension strip comes into play and this opposes the deflecting couple according to Newton's third law motion, and tries to bring the coil back to its original position. It is called the *restoring couple.* The elastic force goes on increasing with the angle of deflection of the coil. At a position where the two couples become equal the coil comes into equilibrium. The greater the deflecting couple the greater is the angular deflection of the coil when it comes into equilibrium.

This instrument can be so constructed that if the poles of the magnent are made concave, lines of force will be along the radii every where and the deflecting couple would be maxium in all positions of the coil and would give us a bigger deflection of the coil for the same magnitude of current.

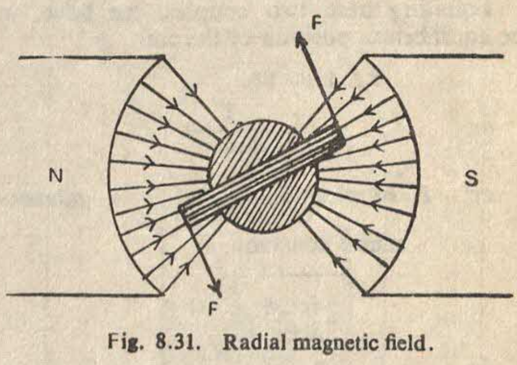


Fig. 8.31. Radial magnetic field.

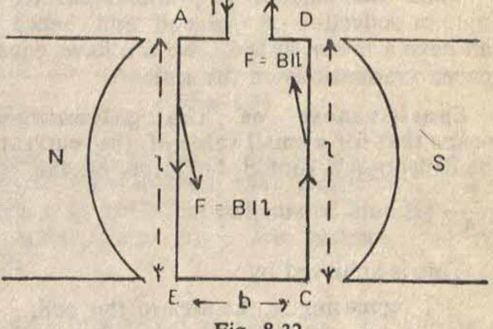


Fig. 8.32.

The expression for the value of the current in terms of the deflection of the coil is developed as shown below

Let l=length of the vertical banch of the coil

b=the mean width of the coil

n=the number of turns of the coil

I=current flowing in the coil

B=the magnetic field

The deflecting force on each of the vertical branches

$$=F=B\,I\,l$$

The moment of the couple set up by these forces

$=B.Il\times b=BIA$ where A is the area of the coil

For n turns of the coil, total moment of the deflecting couple

$$=B.I.A.n$$

Now if T denotes the moment of the restoring couple for unit angle of twist and θ is the angle through which the coil is deflected,

the moment of the *restoring couple*

$$=T\theta$$

Equating these two couples, we have, in the equilibrium position of the coil

$$B.I.A.n=T\theta$$

or $$I=\frac{T}{B.A.n}\theta$$

or $I=k\theta$ where $k=\dfrac{T}{B.A\,n}$ is a galvanometre constant

$$\boxed{I\propto\theta}$$

Thus the current is proportional to the angle of deflection of the coil and hence we can have a *linear* scale *i.e.* we can have equally spaced graduations on the scale.

Sensitiveness of the galvanometer means that for a small value of the current I, the deflection θ should be large or the term $\dfrac{T}{B.A.n}$ should be small.

This is achieved by:

(*i*) increasing A, the area of the coil,

(*ii*) increasing B, the field due to the magnet,

(*iii*) increasing n, the number of turns of the coil, or

(*iv*) by decreasing T, the moment of the torsion or restoring couple per unit angle of deflection.

It is not very profitable to increase the area by increasing the width of the coil as that would decrease the magnetic field in which the coil is placed. Therefore, increasing the area by increasing the length is more useful.

The magnetic field B can be increased by using strong poles of the magnet or having a narrow air gap between the poles.

Increasing n, the number of turns in the coil would increase the resistance of the coil; hence the current will decrease still further.

The moment of the twisting couple per unit angle deflection is decreased by selecting a suitable material for the suspension wire. Phosphor-bronze is very useful from that point of view.

Advantages of Moving coil Galvanometer

(1) It can be placed in any position and its readings are not influenced by the earth's magnetic field.

(2) The magnetic field in which the coil is suspended is so strong that any external magnetic influence would not affect its working.

(3) It can measure currents upto 10^{-9} ampere and hence it is very sensitive.

(4) It can be converted into an ammeter or voltmeter very easily.

(5) With a suitable modification it can be used to measure electric charge. Such a modified galvanometer is known as a Ballistic Galvanometer.

(6) It can be easily made *dead beat* *i.e.* the coil does not swing from side to side but comes to rest quickly and hence it gives the current more readily.

(7) In this galvanometer, the current is directly proportional to the angle of deflection and therefore the scale can be graduated to read the current directly.

Weston or Pivoted Moving Coil Galvanometer

The D' Arsonval moving coil galvanometer described above requires adjustment and hand-ling. In order that it should be sensitive, the deflection is read by lamp and scale arrangement. Dr. Weston made an improvement because of which it can be easily portable and also it becomes more robust. This modified type of galvanometer is known as Weston moving coil pointer-type galvanometer as the deflection can be directly read by the movement of a pointer on a graduate scale.

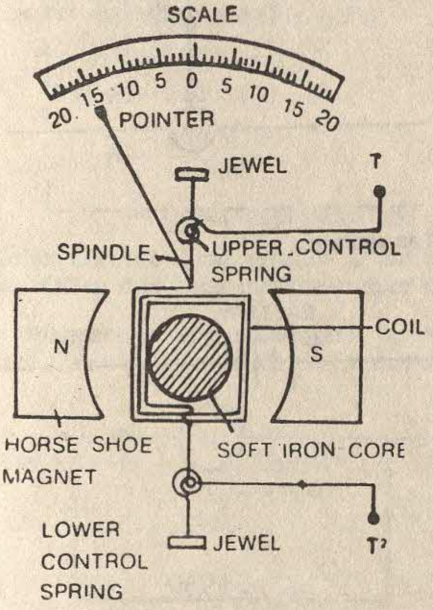


Fig. 8.33. Weston type moving coil galvanometer.

This type of galvanometer is shown in Fig. 8.33. A coil of a wire is provided with two sharp pointed rods. The axis of the two rods passes through the centre of gravity of the coil. These sharp points are held between two jewel bearings between the poles of a permanent horse shoe-magnet. It becomes a magnet whenever current passes through it. Thus this instrument has two magnets : a permanent horse-shoe magnet, in a fixed position, and an electromagnet, free to turn on its axis. Electric connections to the coil are made through two control springs, which hold it so that the pointer attached to the coil shows a zero reading when no current is present. In such a galvanometer, the zero position is often located at the mid-point of the scale.

When there is a current in the movable coil, as the core is magnetized ; a couple acts upon the coil which rotates the coil. As the coil rotates, it does work against the two control springs. Its final position is reached when the couple acting on it just neutralized by the reaction of the springs. When the coil reaches its equilibrium position, these two opposing couples are equal, and deflection angle of the coil is therefore, proportional to the current in it.

The scale of the coil is marked at intervals on either side of the zero centre. Readings are read on this scale by means of a small, light weight pointer attached to the coil.

8.13. AMMETER (USE OF A GALVANOMETER AS AMMETER)

Ammeter is a short name for ampere-meter which means an instrument designed to measure the current (flowing in a circuit) directly in amperes. As the current in the circuit is same every-where, *an ammeter may be placed anywhere in the circuit* **in series** *with it*. Now in order that its insertion in the circuit may not affect the current flowing there, an ammeter must be a *low resistance* instrument.

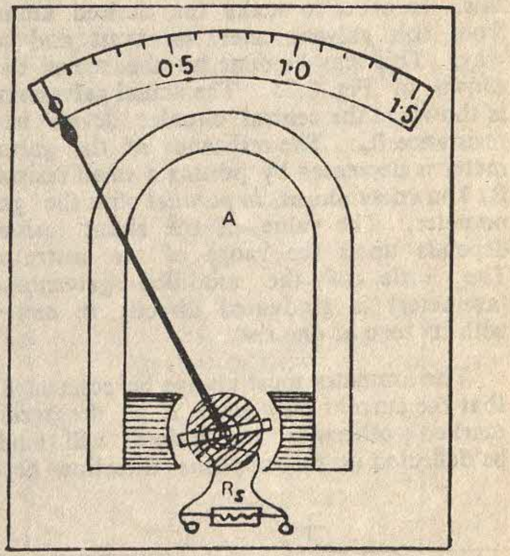


Fig. 8.34.

An ammeter is a modified galvanometer (Fig. 8.34). If it is to be a very sensitive ammeter, it may be a galvanometer without any modification, However, most galvanometers will give full scale deflection for a few

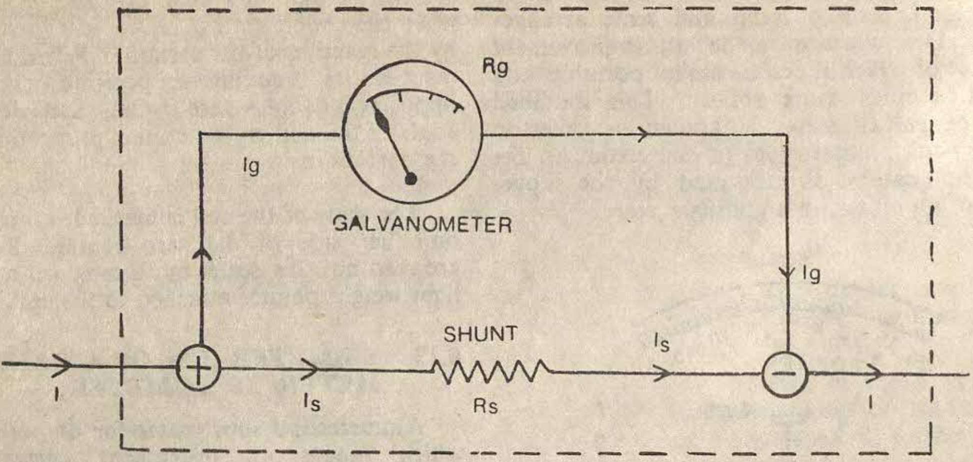


Fig. 8.35. Construction of an ammeter.

milliamperes or less, and so they cannot be used directly to measure currents larger than this. In order to make the desired ammeter from this galvanometer, we must find some way. This may be done by the meter design shown in Fig. 8.35. The actual galvanometer is shown as the central circular device having resistance R_g: The resistance of the galvanometer is decreased by putting a small resistance R_s known as **shunt**, *in parallel* with the galvanometer. The value of the shunt resistance depends upon the range of the instrument. The scale of the modified galvanometer (ammeter) is graduated directly in *amperes*, with its zero at one end.

The ammeter must always be connected so that the current may enter it at the terminal marked + otherwise the pointer will tend to be deflected in the opposite direction beyond the zero of the scale, and thus may get bent or broken. Fig. 8.36 represents the symbol for an ammeter. Fig. 8.37 represents the circuit in which the current is to be measured and Fig. 8.38 represents how ammeter is connected in series in the circuit.

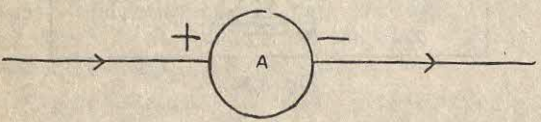


Fig. 8.36.

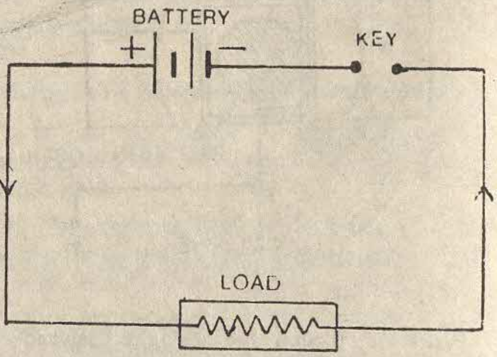


Fig. 8.37.

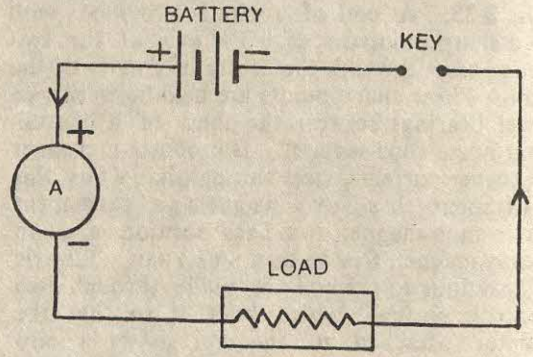


Fig. 8.38.

We can calculate the required resistance of the shunt (R_s), if we apply the rules for a parallel circuit. The shunt is parallel with the galvanometer resistance (R_g), and therefore the voltage drops are equal (Fig. 8.35).

$$I_sR_s=I_gR_g$$

where I_s=current through the shunt

and I_g = current through the galvanometer for full scale deflection.

If the galvanometer has a resistance (R_g) of 100 ohms and gives full scale deflection for 10 milliamperes, we can, for example, convert it to a 0 – 1 amperemeter, that is, a meter that gives full scale deflection for 1 ampere. Note, that at full scale deflection, the current through the galvanometer (I_g) is 10 milliamperes or 0·01 ampere. The other 0·99 ampere (I_s) must then go through the shunt (Fig. 8.39).

$$\because \quad I_s R_s = I_g R_g$$

$$\therefore \quad 0{\cdot}99\, R_s = 0{\cdot}01 \times 100$$

$$\therefore \quad R_s = \frac{0{\cdot}01 \times 100}{0{\cdot}99}$$

$$= 1 \text{ ohm (approximately)}$$

Notice that the shunt resistor is extremely small. Often it is just a piece of copper wire.

In this manner, we can calculate the shunt required for increasing the current range of the galvanometer to any desired value. Frequently one encounters ammeters having more than one range. These meters contain several alternate shunts. The sensitivity of the meter is determined by which shunt is connected across the meter terminals.

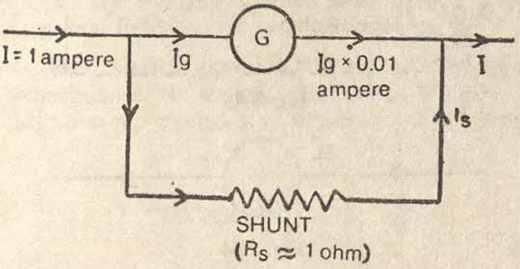


Fig. 8.39

8.14. VOLTMETER (USE OF A GALVANOMETER AS A VOLTMETER)

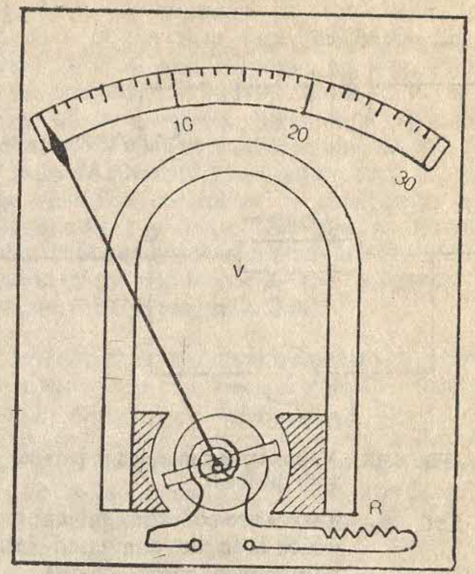


Fig. 8.40.

A voltmeter (Fig. 8.40) is an instrument used for measuring potential difference. As potential difference is directly proportional to the current, and the current is directly proportional to the angle of deflection, therefore a galvanometer can be graduated so as to give the readings of the potential difference directly from the scale. In order that the voltmeter should measure the potential difference between any two points (say P and Q), *it must be placed in parallel with the circuit* (Fig. 8.42). As its insertion should not affect the current flowing in the circuit, it must be a high resistance galvanometer, so that a very small fraction of the current in the main circuit may flow in the instrument. The resistance of the galvanometer is increased by putting a *high resistance in series* as shown in Fig. 8.41.

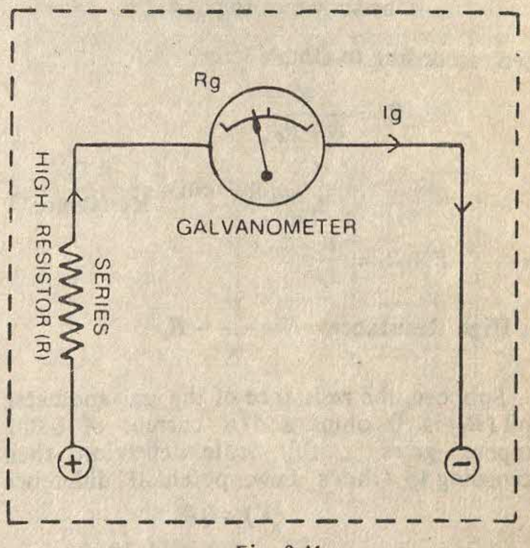


Fig. 8.41.

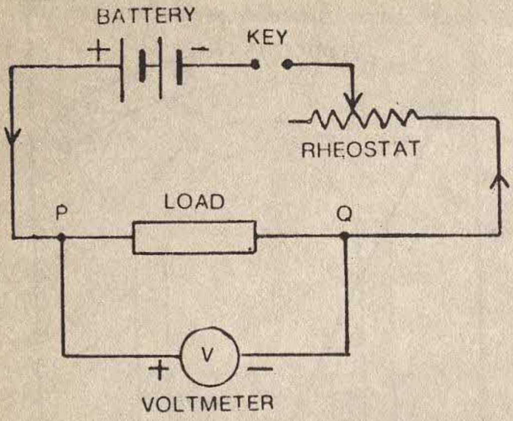


Fig. 8.42. Voltmeter is connected in parallel with the load.

Let R_g = Resistance of the galvanometer which is to be converted into a voltmeter of range V volts.

I_g = Maximum current passing through the galvanometer so as to give full-scale deflection.

R = Resistance connected in series with the coil of the galvanometer as shown in Fig. 8.41.

then, according to Ohm's Law,

$$I_g=\frac{V}{R+R_g}$$

$$\left(\because\ \text{current}=\frac{\text{P.D.}}{\text{Resistance}}\right)$$

or $$R+R_g=\frac{V}{I_g}$$

or High Resistance $=R=\frac{V}{I_g}-R_g$

Suppose, the resistance of the galvanometer coil (R_g) is 10 ohms and a current of 0·001 ampere gives a full scale deflection, then according to Ohm's Law, potential difference

$$(V)=I_gR_g$$
$$=0{\cdot}001\times10$$
$$=0{\cdot}01 \text{ volt}$$

Such a galvanometer can measure voltage only upto 0·01 volt or 10 mV. In order to convert this galvanometer to measure voltage upto say 100 volt, we must add a high resistance R in series with its coil (Fig. 8.43) such that

$$0{\cdot}001=\frac{100}{R+10}$$

or $$R+10=\frac{100}{0{\cdot}001}$$
$$=100000 \text{ Ohm}$$

or High Resistance $=R=100000-10$

or $R=99990$ ohm.

Thus a high resistance of 99990 ohm in series with the coil of the galvanometer is required to convert it into a voltmeter of 0 − 100 V range.

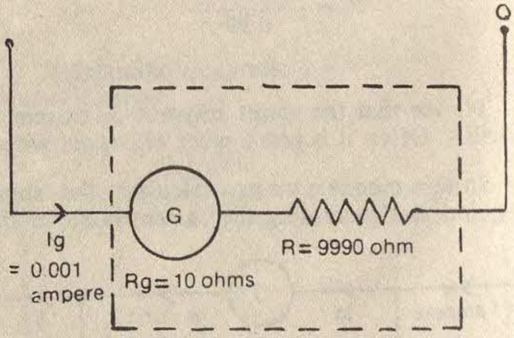


Fig. 8.43

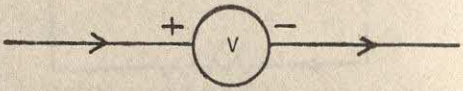


Fig. 8.44

Fig. 8.44 represents a symbol for a voltmeter. The pointer moves over a circular scale graduated directly in volts (Fig. 8.40). The voltmeter must be so connected that the current enters at the terminal marked +.

8.15. ELECTROMAGNETIC INDUCTION

In 1819 Oersted discovered that an electric current produces a magnetic field in the space around it. Efforts started immediately to produce an electric current with a magnetic field. In 1831 this was finally achieved independently by Micheal Faraday in England and by Joseph Henry in the United States. Faraday proved beyond any doubt that *an electric current can be induced in a closed circuit by varying the magnetic field intensity or the number of magnetic lines of force passing through the circuit. The change of magnetic lines of force can be produced by a* **relative motion** *between the circuit and a magnetic field* *produced either by a magnet of by another circuit or conductor carrying an electric current. This phenomenon of production of an electric current in a circuit by the help of a magnetic field is called* **electromagnetic induction.**

The current produced in this way is called **induced current.** In its nature it is no different from other electric currents. The electromotive force (*e.m.f.*) or potential difference producing such current is known as **induced e.m.f.** (or induced potential difference).

The number of magnetic lines of force (or magnetic flux) through a closed circuit may be changed by one of the following ways :

1. by moving a magnet in the vicinity of the circuit,
2. by changing a current flowing in a circuit lying near the given circuit,
3. by varying the distance of the given circuit from another circuit carrying current.
4. by changing the current in the circuit itself, and
5. by moving the circuit itself in the magnetic field.

We shall examine some of Faraday's experiments to understand their significance. Suppose we connect a sensitive galvanometer in a closed conducting loop as snown in Fig. 8.45. A segment of the conductor is poised in the field flux (magnetic lines of force) of a strong magnet. In Fig. 8.45 (*A*), as the conductor is moved down between the poles of the magnet, there is a momentary deflection of the galvanometer needle, indicating an induced current. The needle shows no deflection when the conductor is stationary in the magnetic lines of force. This leads to the observation that the induced current is related to the motion of the conductor in the magnetic lines of force (or the magnetic flux).

Raising the conductor between the poles of the magnet, as in Fig. 8.45 (*B*), results in another momentary deflection of the galvanometer needle, this time in the *opposite* direction. This leads to the observation that the direction of the induced current in the conductor is related to the direction of motion of the conductor in the magnetic field. The *e.m.f.* (potential difference) induced in the conductor is of opposite polarity to that in the first experiment.

Faraday found that he could induce an *e.m f.* in a conductor either by moving the conductor through a stationary magnetic field or by moving the magnetic field near a stationary conductor. He observed that the

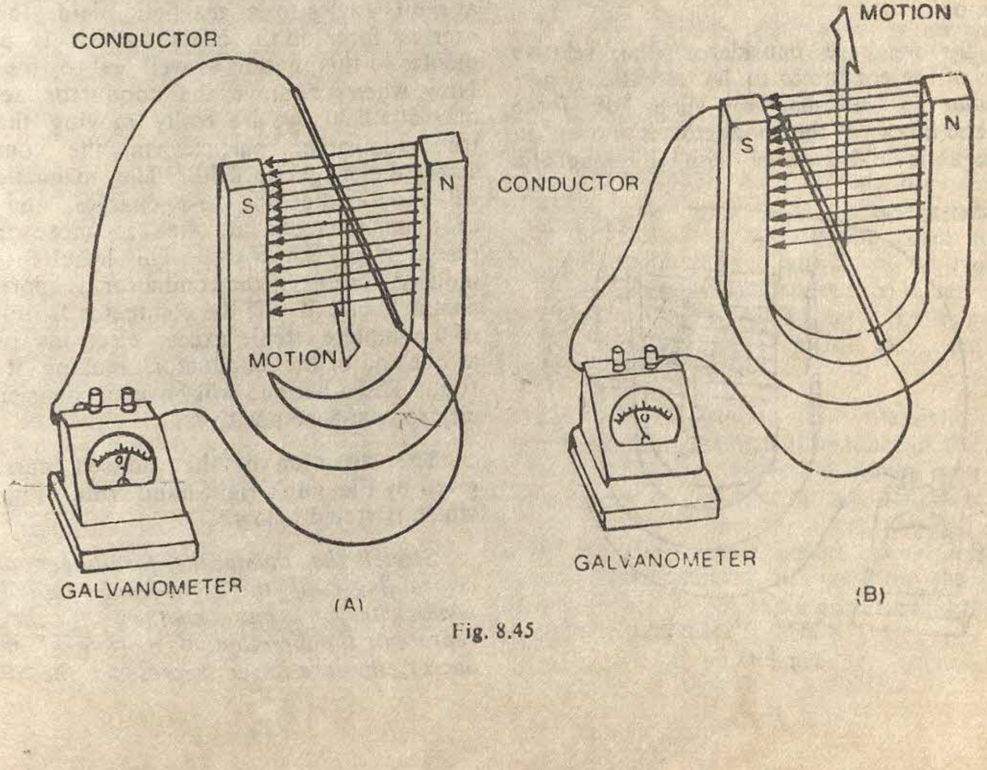
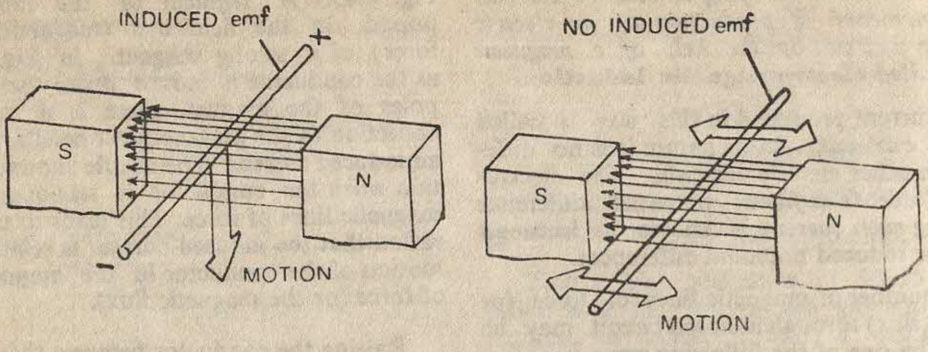


Fig. 8.45



(A) CHANGE IN FLUX LINKAGE

(B) NO CHANGE IN FLUX LINKAGE

Fig. 8.46

direction of the induced current in the conducting loop is reversed with a change in either the direction of motion or the direction of the magnetic field.

Support the conducting loop of (Fig. 8.45) in a fixed position and lift the magnet. It results in a deflection similar to that of Fig. 8.45 (*A*). When the magnet is lowered the galvanometer needle is momentarily deflected as in Fig 8.45 (*B*). The relative motion between the conductor and the magnetic field is the same whether the conductor is raised through the stationary magnetic field or the magnetic field is lowered past the stationary conductor.

So far we have considered the relative motion of the conductor to be essentially *perpendicular* to the magnetic lines of force (magnetic flux). If the conductor is moved in the magnetic field *parallel* with the magnetic lines of force, no *e.m.f.* is induced and no deflection is observed on the galvanometer. See Fig. 8.46.

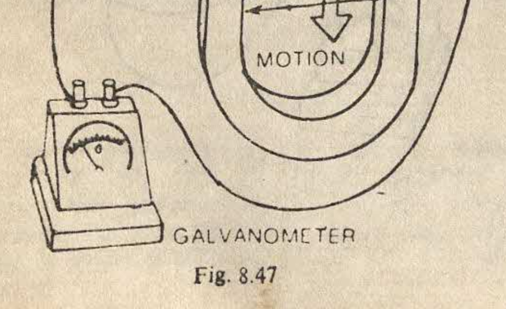


Fig. 8.47

Suppose the conductor is looped so that several turns are poised in the magnetic field as in Fig. 8.47. When the coil is moved down between the poles of the magnet as before, there is a greater deflection in the galvanometer. By increasing the rate of motion of the coil across the magnetic lines of force, greater deflections are produced.

The reason for the generation of the induced current is very simple. When a charge moves at right angles to a magnetic field, the field exerts a force on the charge which is perpendicular to this motion as well as to the field. Now, when we move the conductor across a magnetic field, we are really moving the electrons and other particles in the conductor across the magnetic field. The magnetic field will exert a force on these charges, and some of these electrons are free to move in the direction of the force. This results in the induced current, if the conductor is part of a complete circuit. If the conductor is not part of a complete circuit, excess electrons pile up at one end of the conductor, making it negative. The other end will have a deficiency of electrons and be positive.

The direction of the induced current is given by Fleming's right-hand rule (Fig. 8.48) which is stated below :

Stretch the thumb, the fore-finger and the central finger of the right-hand mutually perpendicular to one another. If the thumb represents the direction of motion of the conductor, the fore-finger represents the direction *of the magnetic field, then the central finger points in the direction in which current is induced in the circuit.*

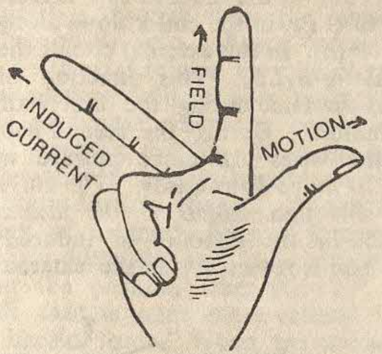


Fig. 8.48

Modern technology is largely dependent on the production and distribution of inexpensive electric power. These accomplishments were made feasible by the discoveries of Faraday which led to the invention of electric generators and transformers.

8.16. ELECTRIC GENERATOR (OR DYNAMO)

The induced current observed in the experiment in Art. 8.15 is usually very small. But one can construct devices to produce large currents for use in industry and homes. Such devices are called *electric generators*. A small generator used with a bicycle and other vehicles is popularly known as *dynamo*.

An electric generator (or dynamo) is, thus, a machine used for generating electric current by mechanical means, or a machine in which mechanical energy is changed into electrical energy. It works on the principle of electromagnetic induction *i.e.* whenever the number of magnetic lines of force passing through a conductor (a wire or a rod) is varied, an emf (or current) is induced in it. The strength of the emf (or current) produced is directly proportional to the strength of the magnetic field and the speed with which the conductor moves. The direction of the induced current is given by Fleming's right hand rule (Art 8.15).

When the electric current produced by a dynamo or an electric generator *changes its direction of flow continuously and periodically in a circuit several times in a second*, the current is known as an *alternating current* (A.C.) and the machine that produces it is known as an *alternating current generator (A.C Generator)* or A.C. Dynamo. An alternating current is shown graphically as in Fig. 8.49 (*i*). When

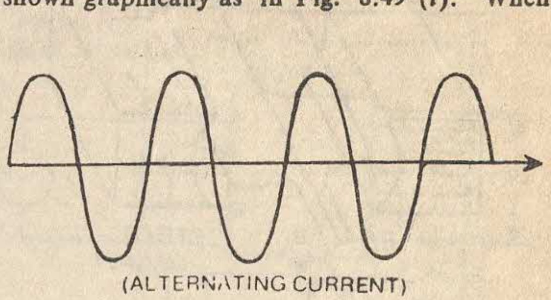


Fig. 8.49 (*i*)

the electric current produced always flows *in and the same direction and has a constant strength*, it is known as *direct current* (D.C.)

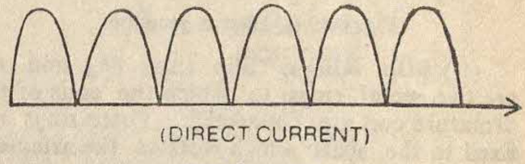


Fig. 8.49 (*ii*)

[Fig 8.49 (*ii*)] and the machine that produces it is known as *direct current generator* (D.C. Generator) or D.C. Dynamo.

A simple electric generator is shown in Fig. 8.49 (*a*) It consits of four main parts :

(*i*) **Armature**. Armature *ABCD* consists of a large number of loops or coils of insulated wire wound on a soft iron drum, [fig. 8 49 (*b*)] or ring. It revolves round an axle between the two poles of a strong magnet and this cuts the magnetic lines of force running from north pole to the south pole. This drum or ring of soft iron serves two purposes : (*a*) it serves to support the coils and (*b*) increases the magnetic field by substituting iron for air core for magnetic lines of force.

(*ii*) **Field Magnets**. The magnetic field is produced by a permanent magnet in the case of very small low power dynamos and by electromagnet in the case of big dynamos. In the latter case the electromagnet (*N* and *S*) is excited by the current generated by a small direct current generator mounted on the same axle and driven by the same power which keeps the dynamo armature rotating.

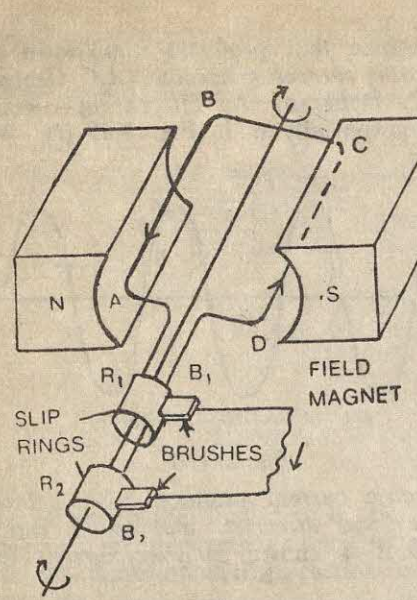


Fig. 8.49 (a) Electro generator.

(*ii*) **Slip Rings.** Slip rings (R_1 and R_2) are two metal rings to which the ends of the armature coil are connected. These rings are fixed to the shaft which rotates the armature coil and thus they also rotate along with the armature.

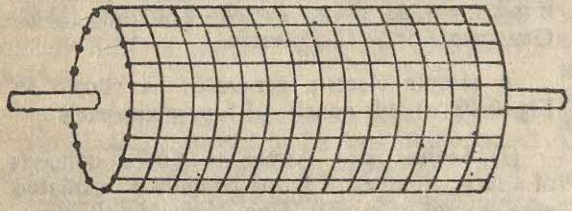


Fig. 8.49. (*b*)

(*iv*) **Brushes.** These are two flexible metal plates or carbon rods (B_1 and B_2) which are fixed and constantly touch the revolving rings. It is with the help of these brushes that the current is passed on from the armature and rings to the main wires which supply the current to the lamps (*L*) in the streets and houses.

Working. The principle of working of an electric generator will be clear from Fig. 8.49 (*a*).

Suppose the armature coil *ABCD* rotates in the anticlockwise direction. As it rotates, the magnetic flux linked with it changes and the current is induced in the coil, the direction of which is given by Fleming's Right Hand Rule. Codsidering the armature to be in the vertical position and as it rotates anticlockwise, the wires *AB* move downwards and *DC* move upwards the direction of the induced *emf* is from *B* to *A* and *D* to *C i.e.* in the coil it flows along *DCBA*, Fig. 8.49 (*a*). In the external circuit the current flows along B_1LB_2. This direction of current remains the same during the first half turn of the armature. During the second half revolution, the wires *AB* move upward while the wires *CD* move downwards. The current flows in the direction *ABCD* in the armature coil, Fig. 8.50 *i.e.* the direction of induced current in the coil is reversed. In the external circuit the current flows along B_2LB_1. Therefore, the direction of the induced *emf* and the current changes in the external circuit also after every half a revolution. Hence the current thus produced is **alternating** in nature (Fig. 8.51).

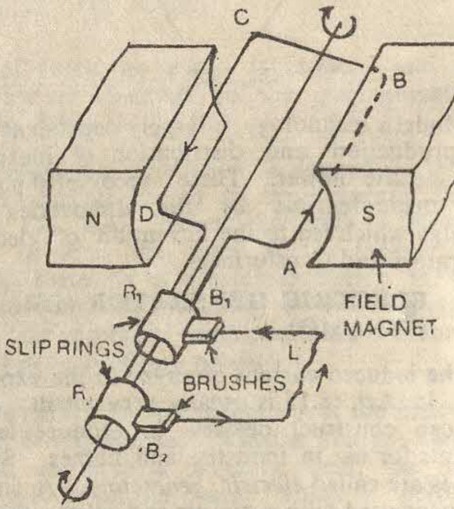


Fig. 8.50.

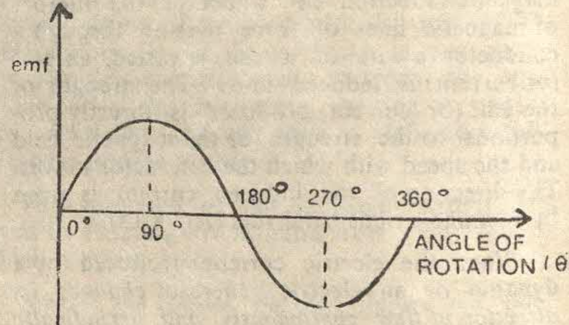


Fig 8 51.

However, the magnitude of the induced *emf* and hence that of the induced current is not constant. When the coil is in the vertical position $\theta=0^\circ$, maximum number of lines of force is passing through it but the number of lines of force cut is zero. Hence induced *emf* is zero. As the coil rotates, the rate of cutting of magnetic lines of force goes on increasing and it is maximum when the coil is in the horizontal position, $\theta=90^\circ$. Thus the magnitude of the induced *emf* is maximum. When the coil rotates further the rate of variation in the number of magnetic lines of force cut by the coil again decreases and induced *emf* falls to zero at the position when $\theta^\circ=180^\circ$. The coil in this case is once more vertical to the magnetic lines of force. When the coil rotates further, the induced *emf* and hence induced current starts in the opposite direction and rises to the maximum value at $\theta=270^\circ$ and again falls to zero at $\theta=360^\circ$, the direction remaining the same. These changes are shown in Fig. 8.51 graphically. Such a current which changes direction after equal intervals of time is called an alternating current and the device shown shown in Fig. 8.49 (*a*) is called an A.C. generator or A.C. dynamo. Most power stations constructed these days produce A.C. in India ; the A.C. changes direction after every $\frac{1}{100}$ second, *i.e.*, the frequency of A.C. is 50 Hz. We can very well represent the voltage (V) of the mains supply in India by the relation

$$V=V_0 \sin 2\pi\nu t$$

where $V_0=220\sqrt{2}\ V$ and $\nu=50$ Hz, V_0 is the *peak* voltage. One usually quotes the root mean square (r.m.s.) voltage, which is

$$\frac{V_0}{\sqrt{2}}=220\ V.$$

A very important advantage of A.C. is that it can be transmitted over long distances without much energy loss.

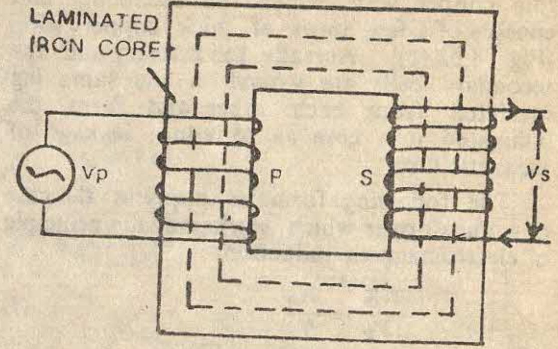
A *DC* or direct-current generator can be constructed with a slight modification of the above *AC* generator. We use the same field magnet and armature coil, but instead of slip rings, we use *split rings* or a *commutator*.

8.17. TRANSFORMER

Transformer is a device used in modern practice.

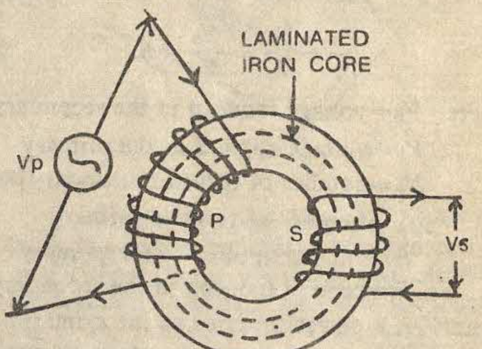
(*i*) for converting an A.C. of high *emf* and low current strength into an A C. of lower *emf* and a high current strength or

(*ii*) for converting an A.C. of low *emf* and high current strength into an A C. of higher *emf* and of low current strength.



(STEP-UP TRANSFORMER)

(a)



(STEP-DOWN TRANSFORMER)

(b)

Fig. 8.52.

A transformer used for the first purpose is known a **step-down transformer** [Fig. 8.52 (*b*)] and the one used for the second purpose is known as **step-up transformer** [Fig. 8.52 (*a*)].

In a general, a transformer consists of two coils wound round a core of soft iron wires or plates bent into the form of a ring or a rectangular frame but *insulated from each other*. An *alternating current* is passed into one of the coils, known as *primary coil* (P) and an alternating current of the same type but of different *emf* and current strength is produced in the second coil known as *secondary coil* (S). In a step-up transformer, the primary coil consists of a few turns of thick insulated copper wire and the secondary consists of a very large number of turns of thin copper wire

[Fig. 8.52 (*a*)]. In a step-down transformer, the primary coil has a large number of turns of thin copper wire while the secondary coil consists of a few turns of thick copper wire, [Fig. 8.52 (*b*)]. Actually the primary and the secondary coils are wound on the same leg insulated from each other and form the laminated iron core as to reduce leakage of magnetic flux.

The following formulas apply in the case of a transformer which works on the principle of electromagnetic induction.

$$\frac{V_S}{V_P}=\frac{N_S}{N_P} \qquad \ldots(i)$$

$$V_S I_S=\text{efficiency}\times V_P I_P \qquad \ldots(ii)$$

When the efficiency is 100%,

$$V_S I_S=V_P I_P \qquad \ldots(iii)$$

$$\frac{V_S}{V_P}=\frac{I_P}{I_S}=\frac{N_S}{N_P}=K \qquad \ldots(iv)$$

where V_S = voltage induced in the secondary

V_P = voltage applied to the primary

N_S = number of turns in secondary

N_P = number of turns in primary

I_P = current applied to the primary

I_S = current induced in the secondary

$V_P I_P$ = power supplied to the primary

$V_S I_S$ = power supplied by the secondary

K = transformation ratio. It is greater than one in the case of step-up transformer and less than one in the case of step-down transformer.

The efficiency of a transformer is very high and constant over a wide range of power. It is 96%. It is one of the most efficient machines known.

Uses of Transformers

(*i*) *Long Distance Transmission.* When A.C. has to be transmitted over long distances, the energy is lost in the following ways :

1. The line wire being very long has an appreciable resistance and hence a large amount of energy is wasted in the form of heat.

2. In order to keep the resistance of the line wire low, thick copper wires have to be used which increases the cost.

3. There is a large fall of potential along the wire and hence the voltage available at the receiving station is very much decreased.

This loss of energy can be reduced by using a transformer. Suppose, we want to transmit 44000 watts from the generating station to some city at a distance of hundreds of kilometres. It can be transmitted at a voltage of 440 volts and a current of 100 amperes or at a voltage of 11000 volts and a current of 4 amperes (∵ Power = Voltage × current). Since loss of energy due to heat in the first case is very high as compared to the second case, therefore. at the generating station, the step-up transformer is used to convert low voltage A C. into high voltage A.C. This high voltage A.C. at low current is transmitted through the live wires and at the consuming station, high voltage A.C. is converted into low voltage A.C. with the help of a step-down transformer. At the Bhakra Nangal generating station, the step-up transformer converts generated A.C. into 110000 volts. This high voltage A.C. is supplied through the live wires to distant stations. The local power houses convert 110000 volts A.C. into 220 volts or 440 volts A.C. with the help of step-down transformers.

The transmission of D.C. over long distances is not possible because its voltage cannot be increased or decreased whenever desired.

(*ii*) Transformers are used in telegraph, telephone ; wireless transmitting sets ; wireless receiving sets ; television ; at power stations and also for welding and electrical furnaces. For any machinery working on A.C. supply, transformer is a necessity.

8.18. ELECTRIC FUSE

Electricity can be very *dangerous.* It must therefore be treated with great respect and only by those of us who known how to use it and take every safety protection.

The dangers are real. (1) A short circuit can cause a fire, an explosion or shock damage to a person. (2) Faulty insulation can be responsible for a short circuit and all its consequences. (3) Excessive large current can seriously damage equipment. Unless adequate safety precautions are taken electric shocks (which could be fatal) or serious burns are all possible. The heating effect of an electric current is rapid and could be quickly responsible for much damage.

A wire gets hotter as the current flowing in it increases. The electric wiring in a house

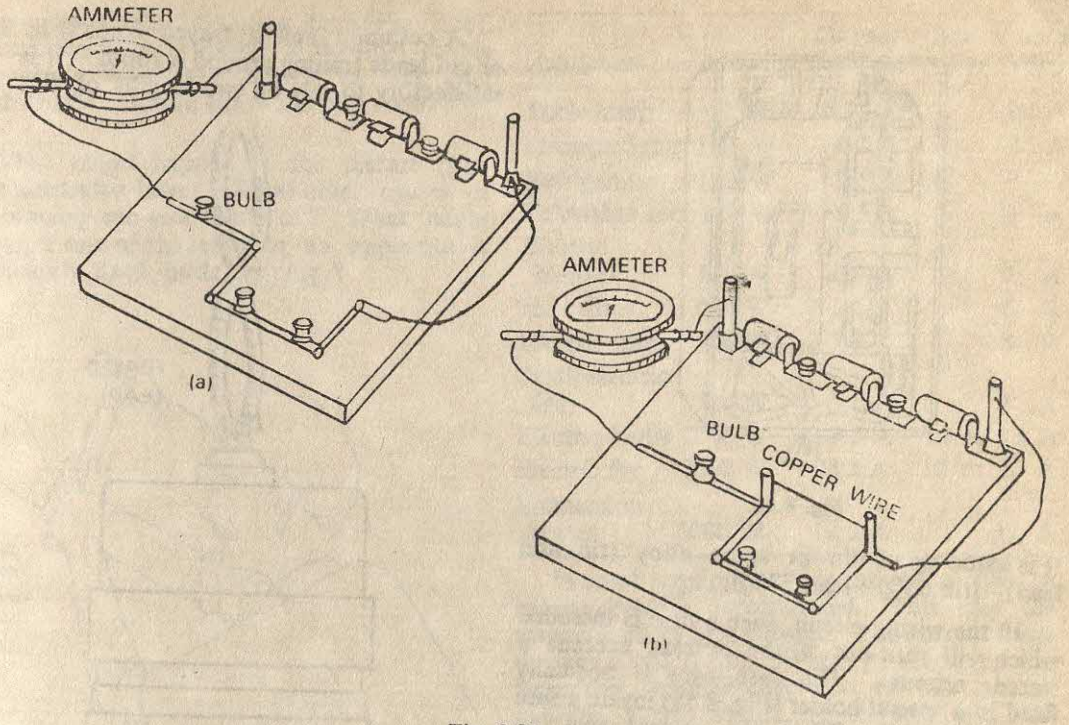


Fig. 8.53.

will stand a certain current without the wires getting too hot to cause any damage. But consider the experiment illustrated in Fig. 8.53.

In the first circuit board, the three lamps will glow equally bright with normal brightness. What will happen if a length of copper wire (copper is a very good conductor) is put across the connecting leads as shown in the second diagram ? What happens to the current ? (If you are in any doubt, try the experiment yourself.)

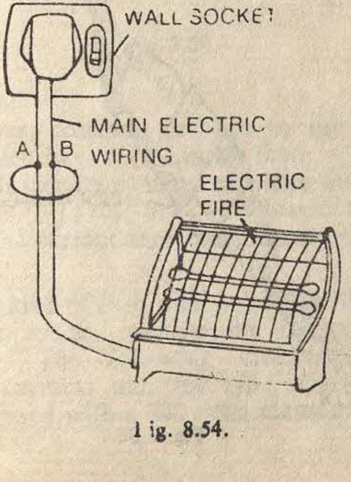


Fig. 8.54.

Now consider what would happen if the leads to an electric radiator touched each other or if a short length of copper wire accidentally fell across the points *A* and *B* in the illustration Fig 8.54. (This is NOT an experiment to try ; it could be *very dangerous* and you might get a shock.)

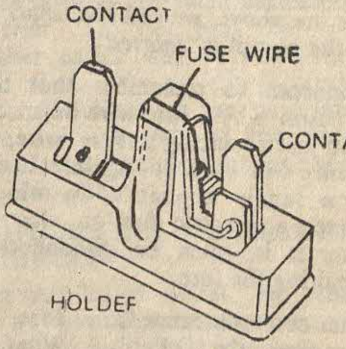


Fig. 8.55.

The current would clearly be large indeed, and the mains wire might get very hot and cause a fire unless there was some automatic way of switching off the current **A small length of wire with a low melting point meets this need.** This is called a **fuse wire.**

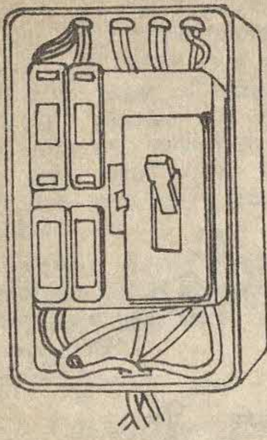


Fig. 8.56.

It is made up of tin or some alloy (tin and lead)—(tin 63%+lead 37%).

In the wiring circuit, such a fuse is included which will burn out if the current exceeds a stated amount. The fuse wire is normally fixed in a special holder (Fig. 8.55) inside a fuse box (Fig. 8.56). When the current gets too great, the fuse burns out and the main electric wiring is protected. It would be difficult to repair the wire in the wall of a room, but it is an easy business to go to the fuse box, take out the fuse holder and replace the fuse wire.

When the two leads to an electric fire or to another electric appliance touch or are accidently joined in some way as illustrated with the electric fire above, we call it a '*short circuit*' or we say the circuit is '*shorted*'.

It is important to remember that there is always a reason why a fuse wire burns out. It is not good just replacing a fuse wire, as the new fuse wire will burn out again. It may be caused by a family appliance, in which case the appliance, an electric fire, an electric iron or whatever it is, must be disconnected first before repairing the fuse.

Another common cause for a fuse blowing is overloading the circuit. What would happen when the current is switched on if an electric kettle, an electric toaster and an electric fire were all plugged into a light socket using two or three way adaptors ?

It is always wrong to connect electric fires, toasters or kettles, which need quite a lot of current, to the electric light circuit, at the same time.

A common fault is frayed leads (Fig. 8.57) or old leads trailing around a room. It is not satisfactory to rely on two lengths of flex tied

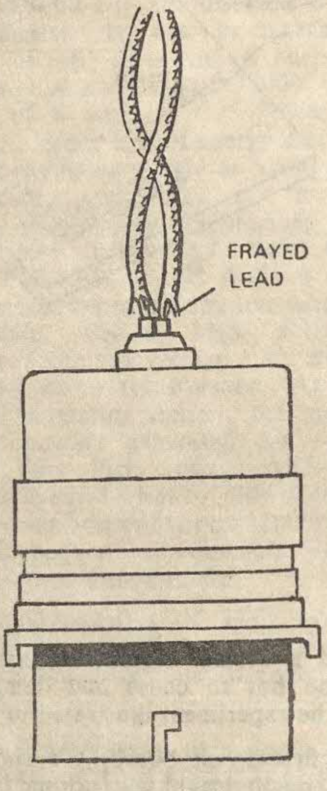


Fig. 8.57.

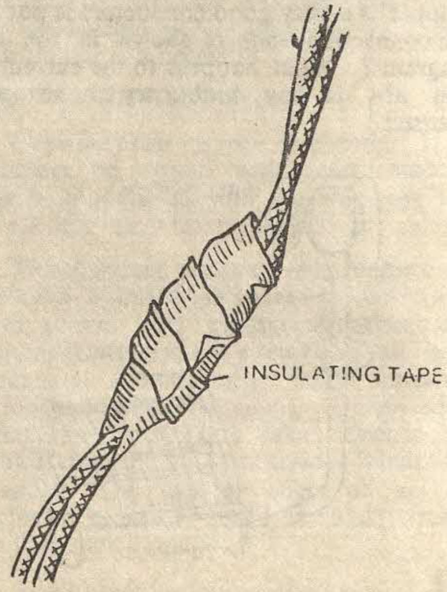
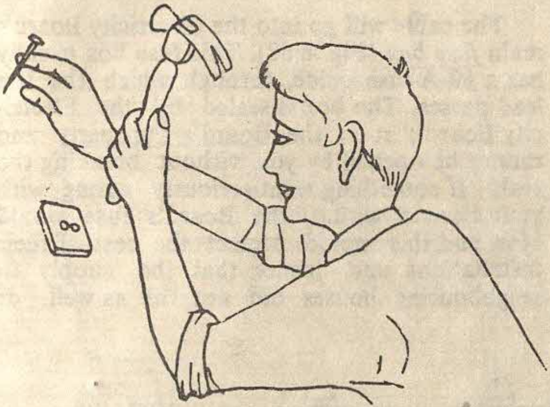
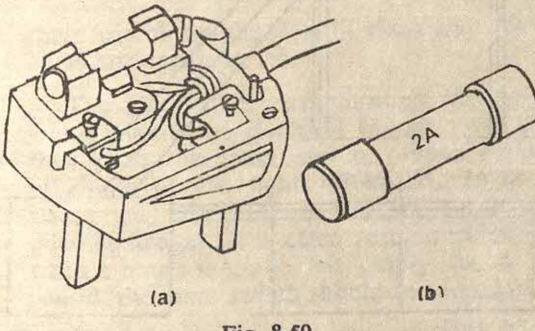


Fig. 8.58.

up together with insulating tape (Fig. 8.58). Such a connection is always a possible source of trouble. Why is it unwise to tack long lengths of flex around the walls of a room ?

What might happen in the picture (Fig. 8.59) illustrated below ? What other causes of fuse-blowing can you think of ? What might happen if one of the leads to an appliance is not securely fixed inside the plug ?





(a) (b)

Fig. 8.59.

It is very common practice to use electric plugs which have a fuse inside them. The fuse in these is usually a little cartridge fuse [Fig. 8.59 (*a*) & (*b*)] ; the fine wire inside melts as soon as the current exceeds the stated value.

What kind of fuse wire be used in the plug will, of course, depend on the particular appliance. The following table shows the probable currents and the type of fuse that might be used with a 240 volts mains supply.

Appliance	*Power*	*Current Required*	*Fuse Needed For Safety*
Table lamp	60 W	0·25 A	2 A
Stronger lamp	120 W	0·5 A	2 A
Refrigerator	120 W	0·5 A	2 A
Television set	120 W	0·5 A	2 A
Electric blanket	120 W	0·5 A	2 A
Hair drier	600 W	2·5 A	5 A
Electric iron	720 W	3·0 A	5 A
Small electric fire	720 W	3·1 A	5 A
Electric kettle	2000 W	8·3 A	10 to 13 A
Electric fire	2000 W	8·3 A	10 to 13 A
Emmersion heater	3000 W	12·5 A	13 A

In some equipment, instead of a fuse, a *cut out device* is incorporated. This uses the magnetic effect of a current. The current flows through a small coil. When it becomes, too large, the magnetic effect due to this current operates a trip switch, which cuts out the current itself.

What is the advantage of this kind of cut-out over an ordinary fuse ?

While replacing a fuse wire, switch off the supply. Take out the fuse carrier from the fuse unit. Loosen the screws of the fuse carrier and remove the melted wire. Take the new fuse wire of the proper size and thread this wire through the small channel or tube in the carrier. Do not pass the wire through any other easier way between the terminal. Tighten the screws in the terminals of the carrier and replace on the porcelain base of the fuse unit. Switch on the supply. Care must be taken that you *insulate* yourself on a dry wooden-board.

8.19. HOUSE-HOLD ELECTRIC CIRCUITS

You have learnt about the generation of electric power and also about how electricity is transmitted around the country.

Electricity is generated at power stations at many places throughout the country. The necessary energy may come from fuel in the form of coal, gas, or oil, or it may come from nuclear energy within the atom (nuclear power station), or it may come from falling water (a hydro-electric power station).

The power station usually produces electricity at 11,000 volts and it is then transmitted around the country at very high voltages. The National Grid operates at 122,000 volts.

Such high voltages are quite unsuitable for domestic purposes. Various institutions, using transformers, bring the voltage down to 220 volts, at which it will reach your home (Fig. 8.60).

In Art. 8.18 we discussed the importance of fuses in electric circuits in order to safeguard electrical appliances and avoid the danger of fire. Fuses, therefore, play an important part in the electrical wiring system in a house.

In domestic wiring, it is important that the third pin at each socket be connected to earth. For this reason three-cored cable is used ; the LIVE wire bringing the electric current is usually coloured *red*, the return wire (often called the NEUTRAL wire) is *black* and the EARTH wire *green*. In order to avoid too much complication in the drawings below, showing the wiring in a house, the earth wire has been ommitted but, of course it is an essential part of the installation.

The Electricity Board's installations. The main cable will pass your house, probably under the road or the pavement outside. A short length of cable joined to the main cable will bring the electricity to your house. This will usually be underground and the cable will enter in the basement or ground floor (Fig. 8.61).

The cable will go into the Electricity Board's main *fuse box* (Fig. 8·62). This fuse box usually has a 60-A fuse inside, through which the live lead passes. The box is sealed by the Electricity Board ; it is the Board's property and cannot be opened by you without breaking the seal. If something went seriously wrong with your electric wiring, the Board's fuse would blow and this would protect the rest of their installations and insure that the supply to neighbouring houses did not fail as well. If

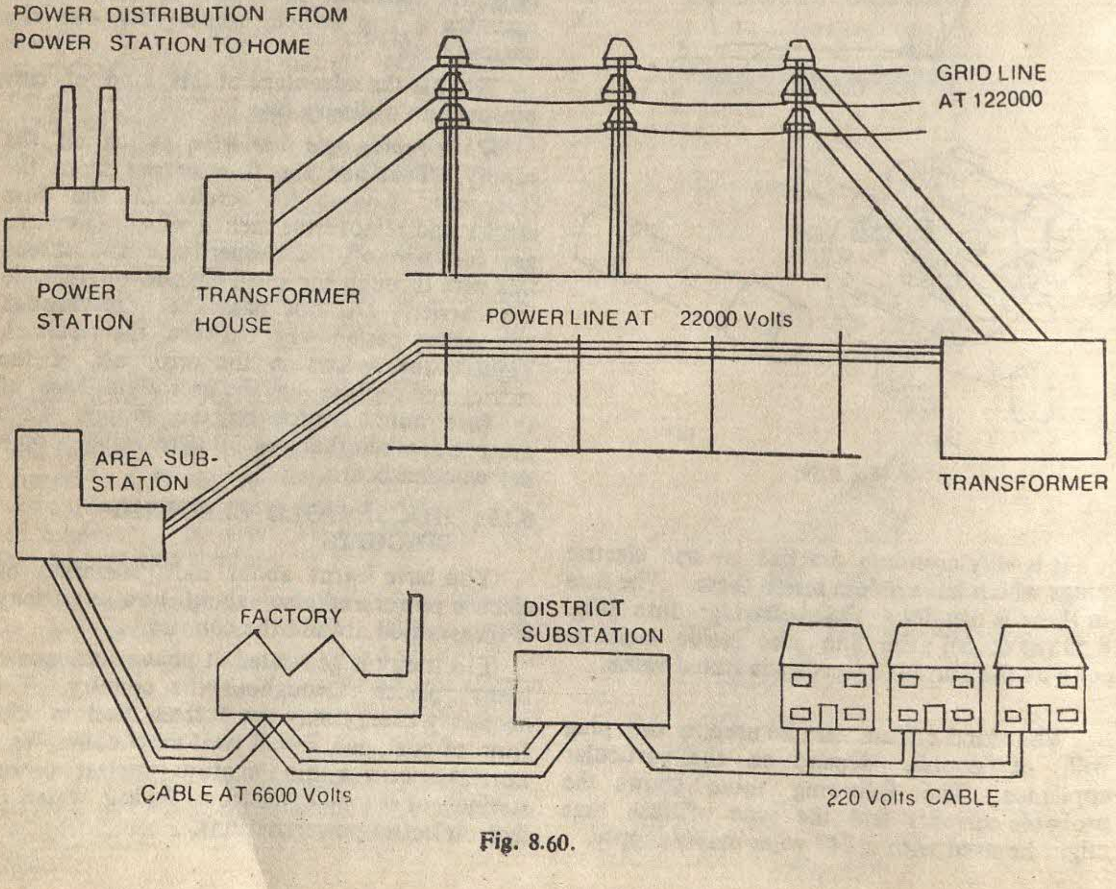


Fig. 8.60.

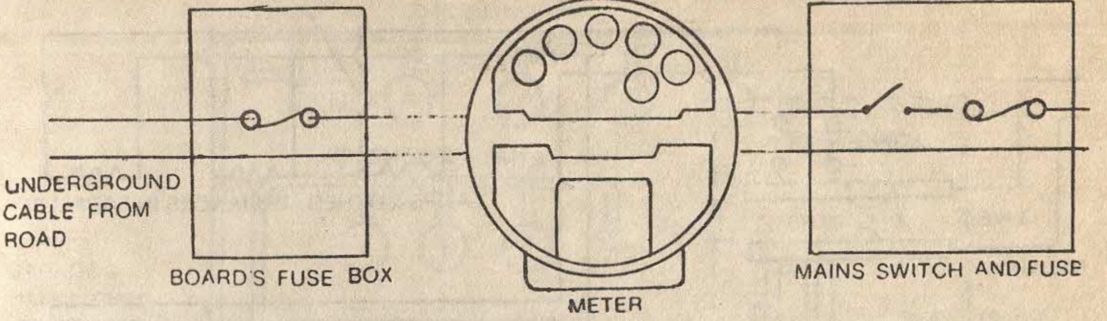


Fig. 8.61

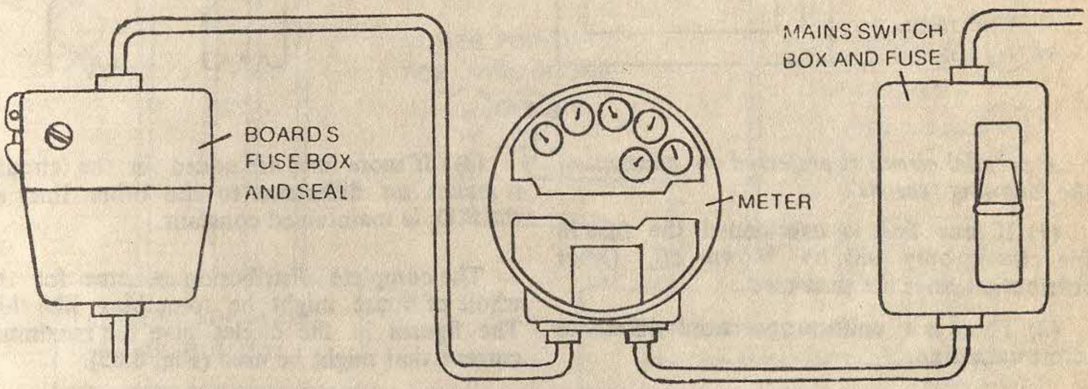


Fig. 8.62

their fuse blows, the Board's electrician has to come and repair it.

The leads then pass through the meter, which records the electrical energy used. They then go to the main switch. When switched off, node of the lights or appliances in the house will work at all and there can be no possible danger. It is often recommended that, when a house is to be left empty for a long period, the main switch should be turned off.

After the main switch, the electricity has to be distributed around the house. What are the requirements going to be ? There must be fuses. There must be leads going to all parts of the house. There are two ways in which this is commonly done, and both are described below.

Distribution fuse box. The leads from the mains switch enter the distribution box, where each is connected to a *bus bar*. The two bus bars consist of two thick copper bars (Fig. 8.63).

From the bus bars in the distribution box, leads go off to all parts of the house. Immediately following the bus bar, the *live* lead passes through a suitable fuse. Then the live and neutral leads, together with the third 'earth' wire, provide electricity in one part of the house. In the diagram only two sets of leads are shown leaving the distribution box, one might be providing lighting up stair, the other lighting in the downstairs rooms.

Suppose the wiring to the upstairs room is such that it will take 5-A with safety. Then the fuse in those leads will be a 5-A fuse. Remembering that a 120-watt lamp will take about 0·5 A and a 750-watt electric fire will take about 3 A, there is a definite maximum to the number of lamps or appliance one can add in parrallel to a particular set of leads without exeeding the 5-A maximum load (Fig. 8.64). As soon as more are wanted, it is necessary to go back to the distribution box and put in another set of leads and another fuse.

It should be noted that all distribution circuts have the same potential difference, usually 220 volts, as they are connected in parallel.

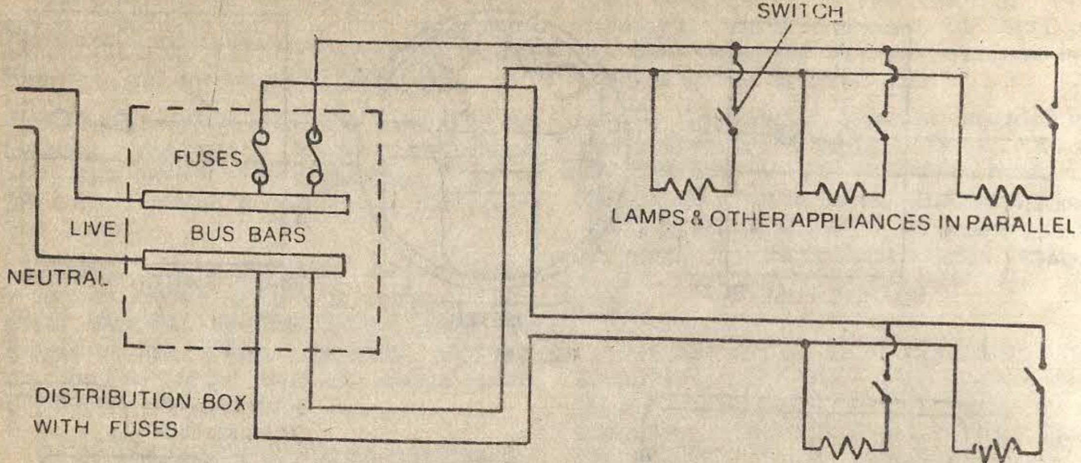


Fig. 8.63

A parallel circuit is preferred on account of the following reasons :

(1) If one line is overloaded the fuse in this circuit only will be blown off. Other distribution lines are protected.

(2) There is a uniform potential difference across each line.

(3) If more lines are added in the circuit, it makes no difference to the other lines as the P.D. is maintained constant.

The complete distribution scheme for the whole of house might be something like this. The figures in the circles give the maximum current that might be used (Fig. 8.65).

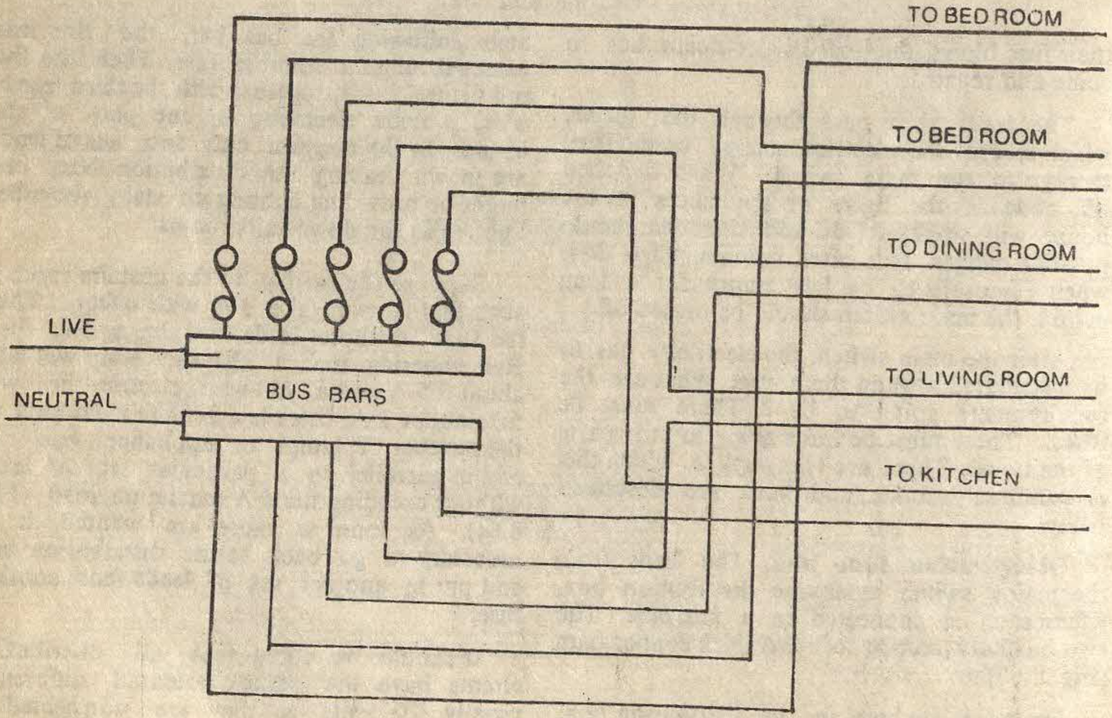


Fig. 8.64

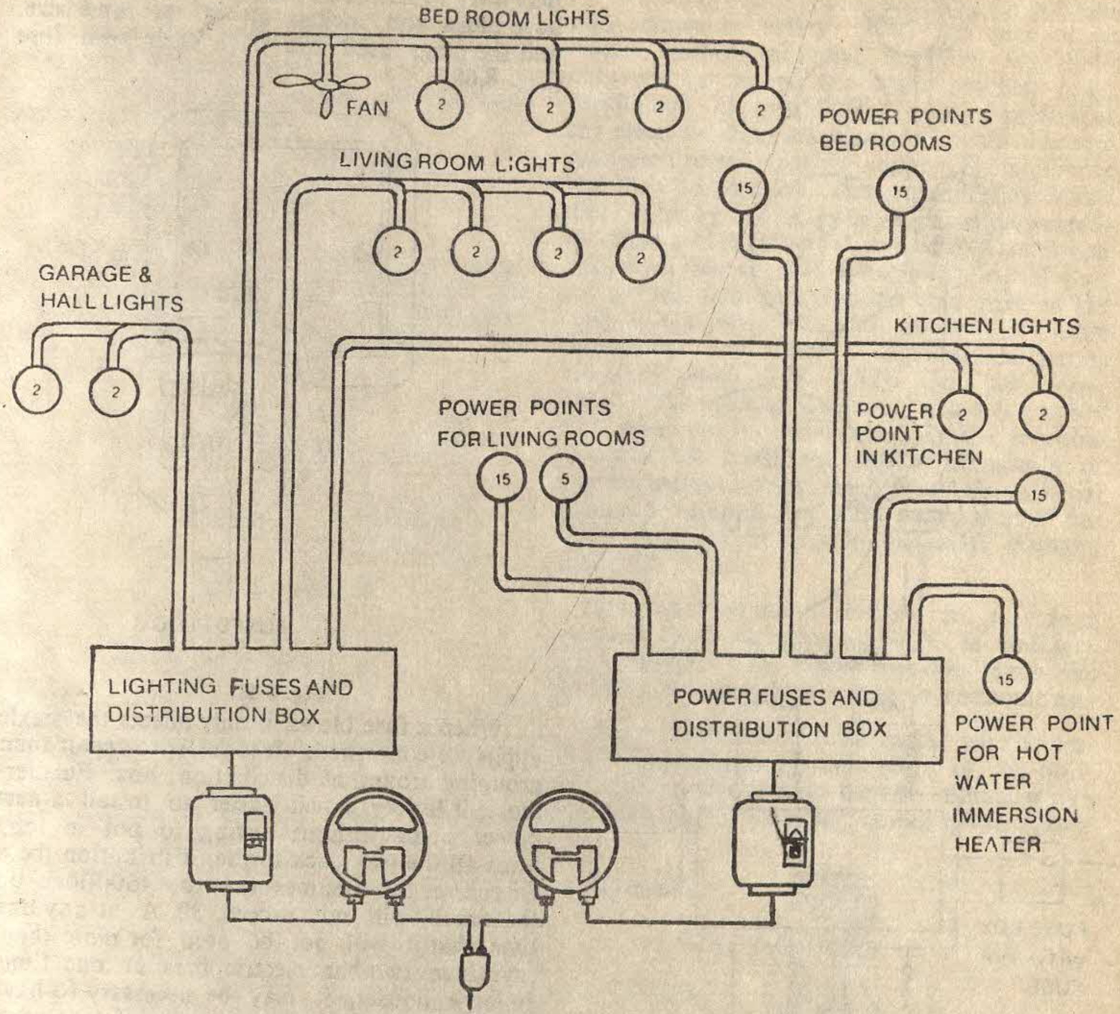


Fig. 8.65. Complete distribution scheme for the whole house

Are there any **disadvantages** in the above scheme ? (*i*) It requires the use of plugs of various sizes as shown in Fig 8.66 and this can be very inconvenient.

(*ii*) Another disadvantage is that when a fuse blows, it puts out all the other lights on the same circuit from the distribution box.

(*iii*) Further more, the fuse has to be repaired at the distribution box, which may be some way away or in an inconvenient spot.

(*iv*) But there is one greater disadvantage. Suppose you have a new electric appliance, which needs a 15-A socket in an upstairs room. To put in the new socket, it is necessary to put in new leads all the way back to the distribution box. Do you see why this will be an expensive business and what a disadvantage this is ?

The ring main system. This system in rapidly replacing the system described above. As its name implies, it consists of a ring circuit. This starts from the main fuse box, which usually has a 30-A fuse, runs round the main rooms of the house and back to the fuse box again, as shown in Fig. 8.67.

There are two routes that the electricity can travel to any one appliance, so even through a 30-A fuse is included, it is usually only necessary to have 15-A cable. It is possible to have plugs and sockets all of the same size, and the plugs used can have their own fuse (Fig. 8.68).

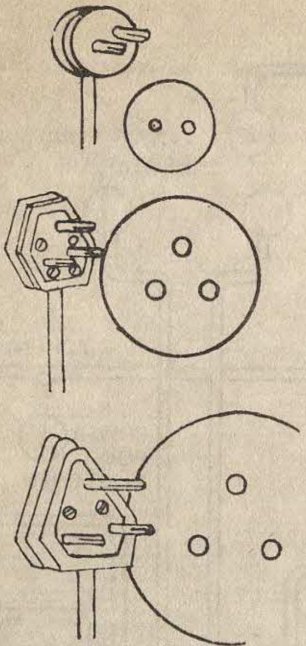


Fig. 8.66

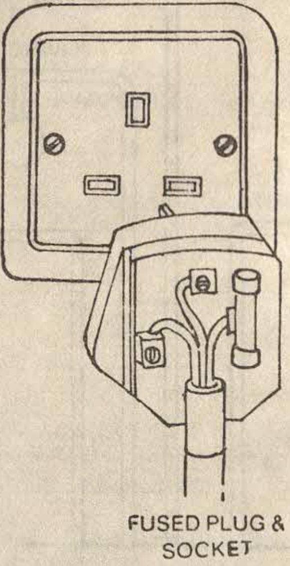


Fig. 8.68.

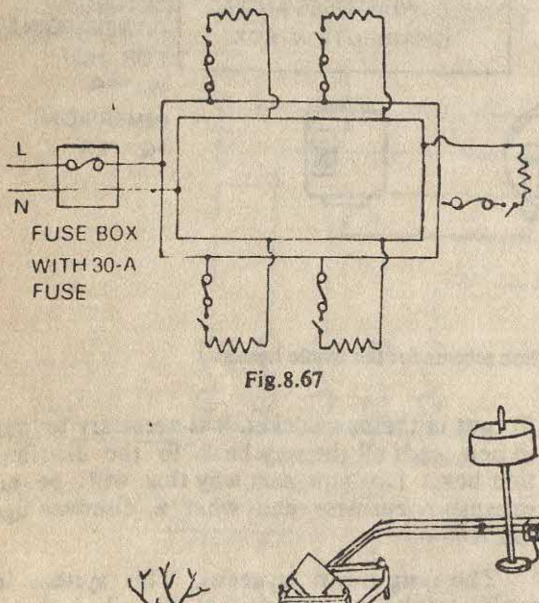


Fig.8.67

When a fuse blows, it only affects the single appliance concerned. It is easier to repair than grouping around at distribution box. Furthermore, it is very much easier to install a new power point without having to put in long leads all the way back to the distribution box. Of course, this assumes that the total load on the circuit will not exceed 30 A at any one time, that it will not be used for more than, say, three two-bar electric fires at one time. In large houses, it may be necessary to have more ring mains running round different parts of the house.

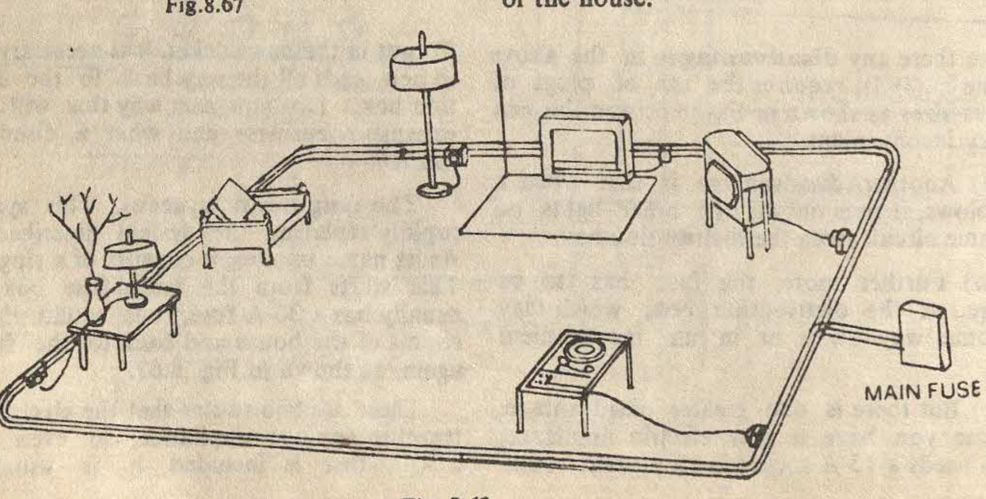


Fig. 8.69

Whatever system is used, it is necessary to have an earth wire as well as the live and neutral leads. The earth lead is connected to the third pin at all the sockets. The earth is shown in the drawing of a ring circuit around a living-room in Fig. 8.69.

8.20. EARTHIG OF ELECTRICAL APPLIANCE AND ITS IMPORTANCE

In electrical terminology *earthing* or *grounding* is a conductor connected to the earth, the absolute potential of which is arbitrarily taken as zero. A common electrical symbol for earthing is shown in Fig. 8.70.

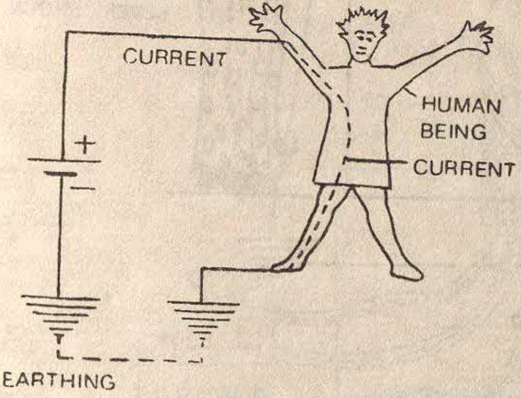


Fig. 8.70.

An important aspect of earthing (or grounding) relates to safety. Take the case of an electric washing machine. Suppose some fault develops in the electric motor wiring (*e.g.*, breakdown of insulation), it is possible that the metal washing machine case could become connected to the electrical supply. The appliance will then become *live*. The unsuspecting house wife could by touching the machine inadvertantly, have a high potential difference established between different parts of her body. An electric current will then pass through this part of her body to the earth. If the current is large enough she will suffer a possibly dangerous electrical shock (Fig. 8·72). On the other hand, if *the washing machine is properly earthed* then when the housewife touches the machine case with her hand, she suffers no passage of electric current, since there exists no potential difference between her and other parts of her body which are at ground potential, namely, zero (Fig. 8.73).

It is now common practice to provide a separate earth (or ground) wire in ordinary house wiring. That is why one now finds the the three pronged electric plug in common use.

Fig. 8.74 shows how this earth wire is employed to earth the case and plate of an ordinary household electric outlet. Some where this earth wire is ultimately connected to either

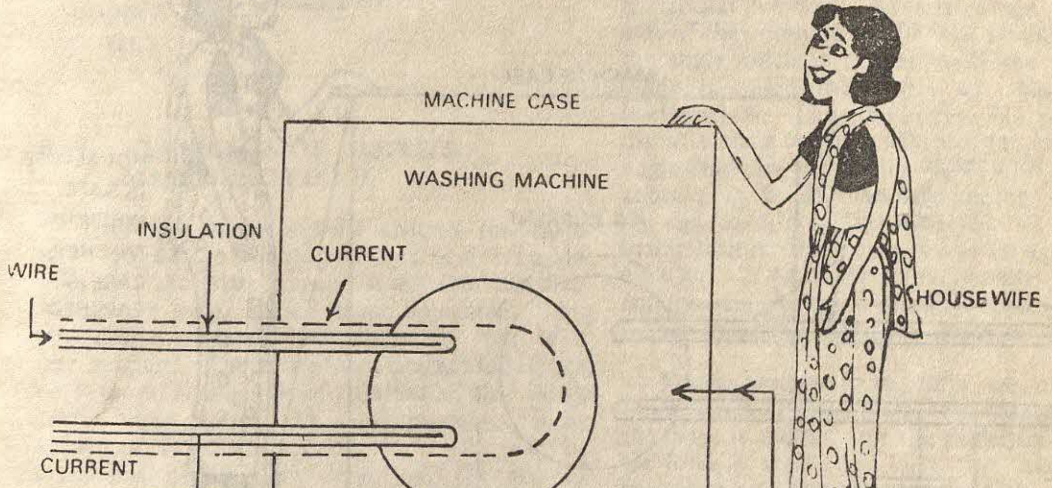


Fig 8.71.

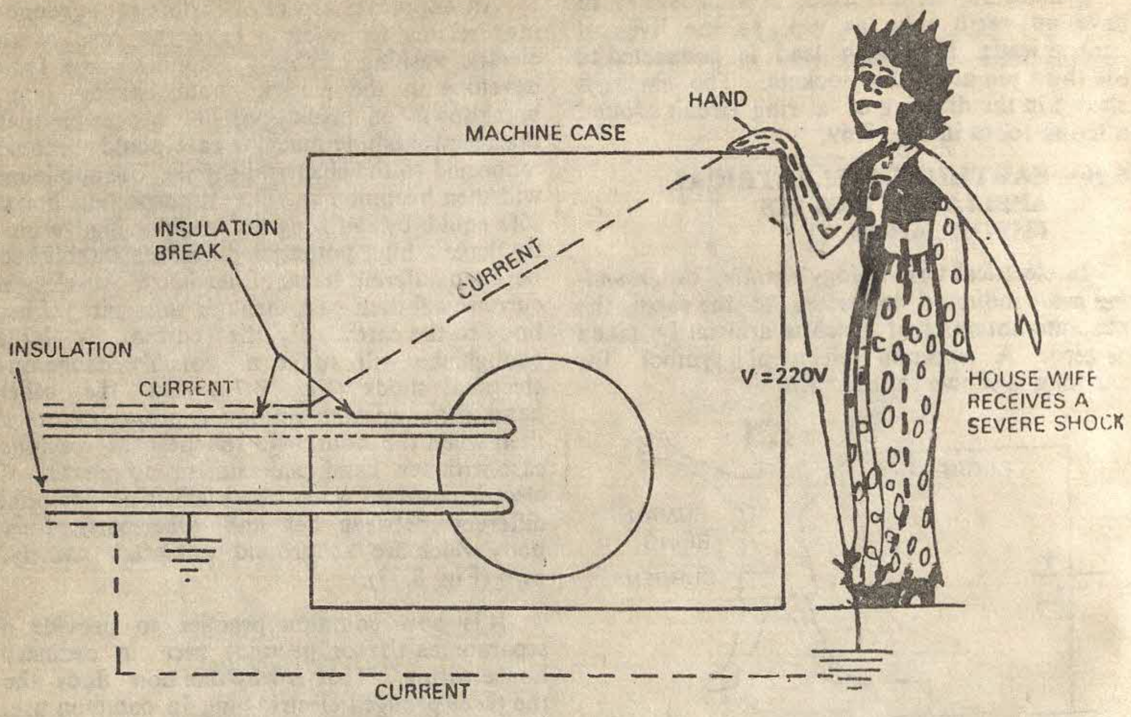


Fig. 8.72

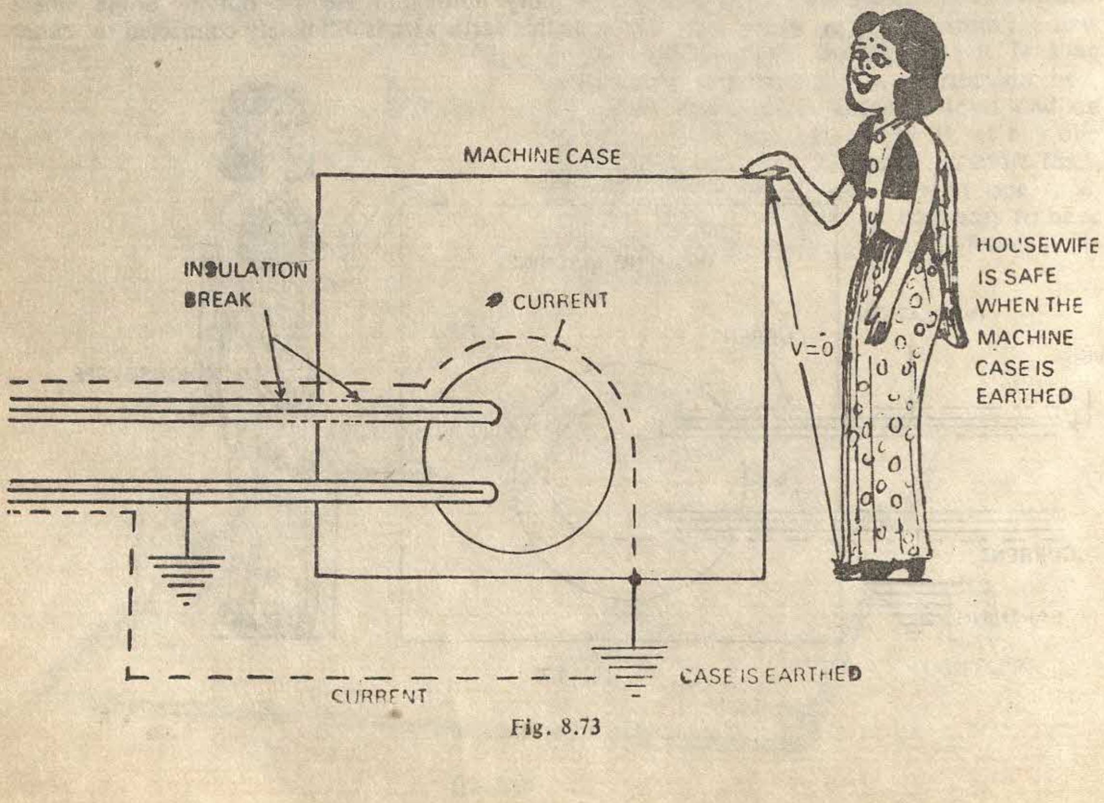


Fig. 8.73

a metal rod driven deep into the ground or simple to a water metal pipe, since the metal pipe usually travels well below ground level from the house to the main water supply.

The earthing of electrical appliance can also save the appliance from damage. If a short circuit occurs in the appliance, a large current will flow through the earth connected wire as it provides an easy path for the current. Due to this current the power supply would be cut and thus no damage would be done to the appliance.

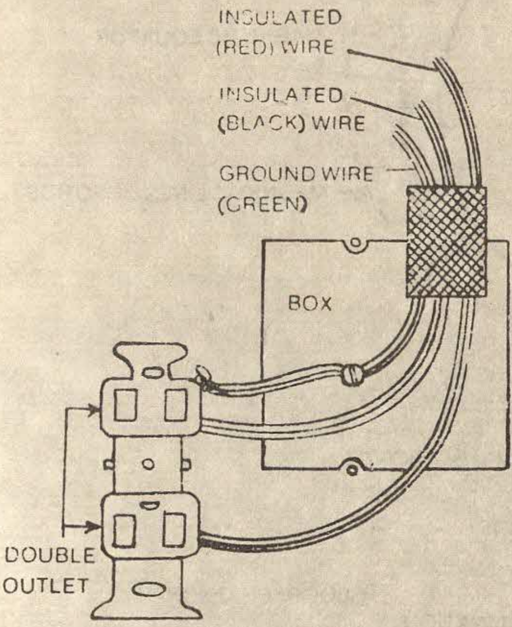


Fig. 8.74.

8.21. ELEMENTS OF EARTH'S MAGNETIC FIELD

There is a magnetic field around the earth as in Fig. 8.75. The earth acts as if it had a relatively short bar magnet, some few hundred kilometres long, buried near its centre. This produces a magnetic field similar to that of a bar magnet. The axis of this magnet does not correspond to the axis of rotation of the earth, but is tilted about 17° with respect to it as shown in Fig 8.75. Since the north pole of a compass needle is, by definition, the end of needle which points *north* when free to rotate in the earth's field, it must be attracted by a south pole. Hence the earth's south magnetic pole is situated near its geographic north-pole, and *vice versa*, as the figure shows. We note that the positions of magnetic poles are not well-defined on the globe—they are spread over an area.

A frictionless compass needle free to rotate in a horizontal plane does not show true geographical north and south directions at a place. It so happens because the magnetic axis and the geographical axis of the earth do not conicide. A vertical plane passing through the direction indicated by the compass is called the *magnetic meridian* [Fig 8.75 *(a)*]. The direction of earth's magnetic field lies in the magnetic meridian and may not be horizontal. A vertical plane along true geographical north and south directions at a place (*i.e.*, passing through geographical axis of earth) is called *geographic meridian. The angle between the magnetic meridian and geographic meridian at a place is known as* the **angle of declination.** Its value is different at different places on the globe. To find the true geographic direction at a place by a compass, one must know the angle of declination at that place.

If we have a compass needle which can rotate in a vertical plane and we keep it in the magnetic meridian, then it will align parallel to the lines of force Around the magnetic poles of the earth, the lines of force are vertical and this compass needle will become vertical. As you move to the magnetic equator, where the field is parallel to the surface of the earth, the magnetic needle will gradually come to the horizontal position. At any other place, the axis of the compass needle will be inclined and the angle which it makes with the horizontal plane is called the **angle of dip** or **the inclination** Thus the angle of inclination or dip at a place on the surface of the earth is the angle made by the earth's field with the horizontal (Fig 8.76). The line joining the points on the earth's surface where the angle of inclination or dip is zero is known as magnetic equator. It passes through Thumba in South India where the space research centre is located. At the magnetic poles, the angle of dipis 90°.

For knowing a force fully we must know three things about it ; (*i*) the plane in which the force is acting ; (*ii*) the direction in which the force is acting and (*iii*) the magnitude of the force. The quantities which determine these three things about earth's magnetic field at a place are known as *elements of earth's magnetic field* Individually, these are known as

(1) angle of declination

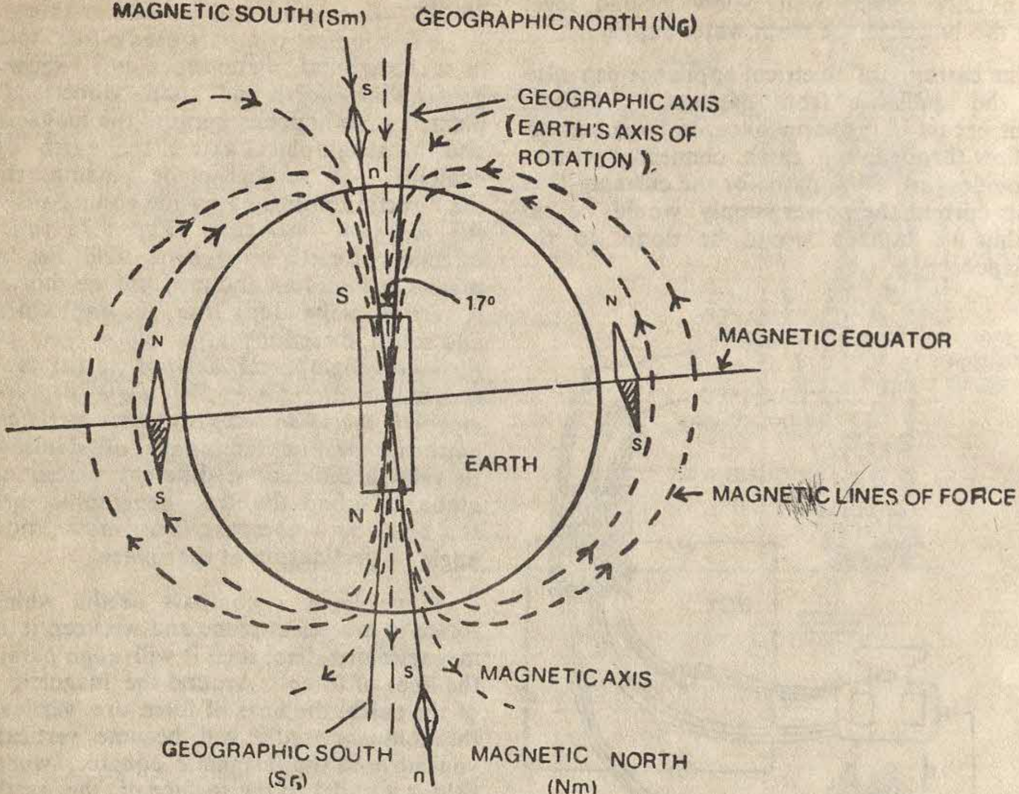


Fig. 8.75

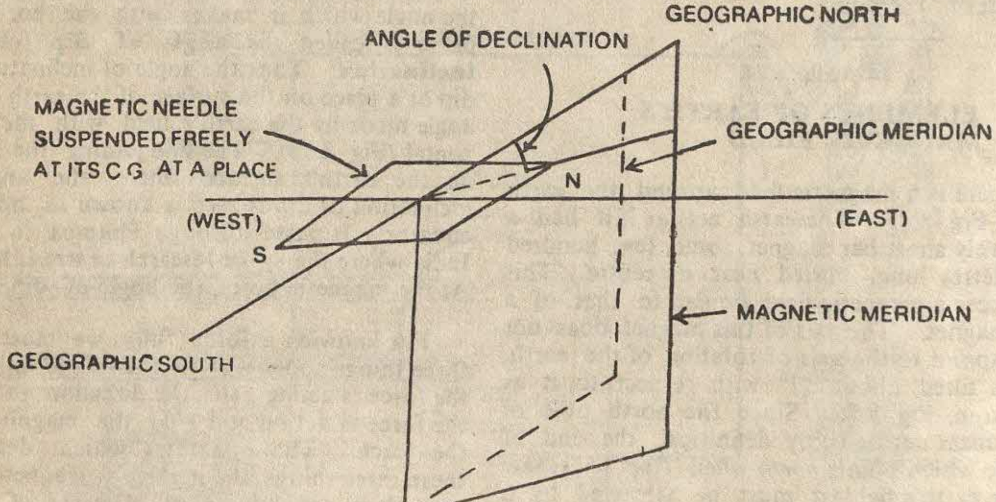


Fig. 8.75 (*a*)

(2) angle of inclination or dip

and (3) the horizontal component of the earth's magnetic field.

Magnetic elements vary irregularly with place at the same time as well as vary with time at the same place. Thus the earth's magnetic field is not as symmetrical as one might imagine. It is, in fact, quite complex.

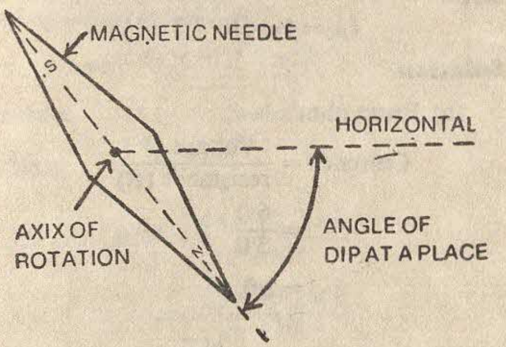


Fig. 8.76.

Knowledge of magnetic elements at a place is of great use in practical life. The angle of declination helps us in preparing and following a geographical map with the help of a compass needle in air or in sea navigation. The variation of angle of dip at a place in the near-about area indicates the presence of iron ores etc. The value of horizontal component of earth's field at a place is of great use in the various calculations involved in various magnetic or electrical phenomena.

Various theories have been put forward to account for magnetism of the earth. But none of these can exactly account for all the observed phenomena associated with earth's magnetism. The general belief is that it is due to the electric currents circulating in the earth's interior.

SOLVED EXAMPLES

Example 1

Find the magnetic field at a distance of 5 cm from a straight wire carrying a current of 20 ampere $\mu_0=4\pi\times10^{-7}$ Tm/A.

Solution

The magnitude of the magnetic field B produced in vacuum at a distance r from an infinitely long straight conductor carrying a current I is given by

$$B=\frac{\mu_0 I}{2\pi r}$$

When the current I is expressed in ampere and the distance r in metre, the magnetic field B is in tesla (symbol T). Here μ_0 is the permeability in vacuum and is exactly equal to $4\pi\times10^{-7}$ Tm/A.

Here, $r=$ cm $=0{\cdot}05$ m

$I=20$ ampere

$$\therefore \quad B=\frac{4\pi\times10^{-7}\times20}{2\pi\times0{\cdot}05}$$

or $B=8\times10^{-5}\ T$

Example 2

A straight conductor, carrying a current of 2 ampere, is placed in a magnetic field of 0·1 tesla. Find the force experienced by it. What is its own magnetic field at a distance of 1 cm from it ? ($\mu_0=4\pi\times10^{-7}$ Tm/A).

Solution

The force (F) experienced by a straight conductor of length (l), which is perpendicular to both the direction of the magnetic field (B) and of the current (I) is given by

$$F=BIl$$

$\therefore$ Force experienced per unit length

$$=\frac{F}{l}=BI$$

Here, $I=2$ ampere

$B=0{\cdot}1$ tesla

$\therefore$ Force experienced by the straight conductor per unit length $=0{\cdot}1\times2$

$=0{\cdot}2$ N

The magnetic field due to the straight conductor $=B=\dfrac{\mu_0 I}{2\pi r}$

Here, $r=1$ cm $=10^{-2}$ m ;

$I=2$ ampere & $\mu_0=4\pi\times10^{-7}$ Tm/A

$$\therefore \quad B=\frac{4\pi\times10^{-7}\times2}{2\pi\times10^{-2}}$$

$$=4\times10^{-5}\ \text{T}$$

Example 3

A coil consists of 1000 circular turns of thin wire with an average radius of 0·1 m. If the current in the coil is 10 A, find the magnetic field at its centre due to (*a*) one turn ; (*b*) the entire coil.

$\mu_0=4\pi\times10^{-7}$ Tm/A

Solution

The magnitude of the magnetic field (B) produced at the centre of the circular coil having one turn is given by

$$B=\frac{\mu_0 I}{2r}$$ where I is the current and r is its radius

(a) ∴ For any one turn, the magnetic field has a magnitude

$$B=\frac{\mu_0 i}{2r}$$

$$=\frac{4\pi\times10^{-7}\times10}{2\times0{\cdot}1}$$

$$=\frac{4\times3{\cdot}14\times10^{-7}\times10}{2\times0{\cdot}1}$$

$$=6{\cdot}28\times10^{-5}\text{ T}$$

(b) If the circular coil has n turns, the field produced is n times that produced due to a single turn because the field due to each turn is in the same direction.

Hence, for 1000 turns, the magnetic field has a magnitude$=1000\times6{\cdot}28\times10^{-5}$ T

$$=0{\cdot}0628\text{ T}$$

Example 4

Two parallel wires carry currents of 10 A and are separated by 1 mm. What is the force on a 2 m long portion of the wire ?

$$\mu_0=4\pi\times10^{-7}\text{ Tm/A}$$

Solution.

The force per uint length $\frac{F}{l}=\frac{\mu_0 I_1 I_2}{2\pi r}$

Here, $I_1=I_2=10$ A

$r=1$ mm

$=10^{-3}$ m

$$\therefore\quad \frac{F}{l}=\frac{4\pi\times10^{-7}\times10\times10}{2\pi\times10^{-3}}$$

$$=0{\cdot}02\text{ Nm}^{-1}$$

Thus the force on a 1 m segment of the wire is 0·02 N. The force on a 2 m segment is twice this force, or **0·04 N.**

Example 5.

Two long straight wires, each of length 0·50 m and separated by a distance of 1·0 cm, are connected to a battery, as shown in Fig. 8.77. The resistance of the circuit external to the battery is 3·0 ohm, and the applied voltage is 6·0 V.

(a) What is the current in the circuit ?

(b) What is the magnitude of the force between the wires ?

(c) Is this force one of attraction or repulsion ?

$$(\mu_0=4\pi\times10^{-7}\text{ Tm/A}).$$

Solution.

(a) From ohm's law,

$$\text{Current } I=\frac{\text{Voltage }(V)}{\text{resistance }(R)}$$

$$=\frac{6{\cdot}0}{3{\cdot}0}$$

$$=\mathbf{2{\cdot}0\text{ A}}$$

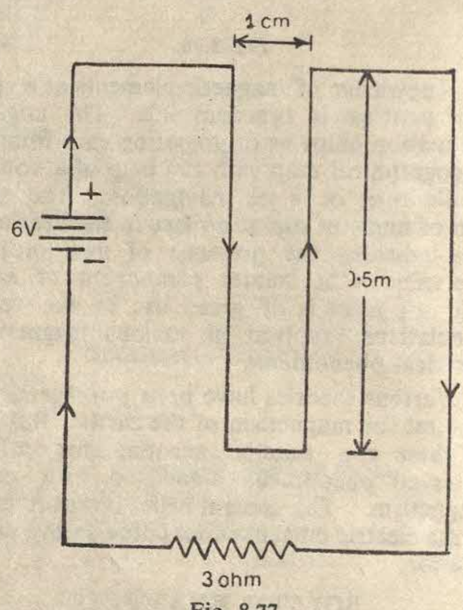


Fig. 8.77

(b) The force between two wires of length l separated by a distance r is

$$F=\frac{\mu_0 I_1 I_2 l}{2\pi r}$$

Here, $I_1=I_2=2{\cdot}0$ A ; $l=0{\cdot}5$ m ; $r=1$ cm $=0{\cdot}01$ m

$$\therefore\quad F=\frac{4\pi\times10^{-7}\times2{\cdot}0\times2{\cdot}0\times0{\cdot}50}{2\pi\times0{\cdot}01}$$

$$=\mathbf{4{\cdot}0\times10^{-5}\text{ N}}$$

(*c*) Since the currents are in opposite directions in the two wires, the force is one of **repulsion.**

Example 6.

At what distance will a straight conductor carrying current of 2 A. produce a magnetic field of 10^{-5} tesla ? How much force will be experienced by another straight wire parallel to and at that distance from the first one and carrying a current of 3 A ?

$$\mu_0=4\pi\times10^{-7}\text{ Tm/A}$$

Solution.

Since $B=\dfrac{\mu_0 I}{2\pi r}$

$$\therefore\quad 10^{-5}=\frac{4\pi\times10^{-7}\times2}{2\pi\times r}$$

$$\therefore\quad r=\frac{4\pi\times10^{-7}\times2}{2\pi\times10^{-5}}$$

$$=4\times10^{-2}\text{ m}$$

$$=4\text{ cm}$$

Again

$$\text{Force per unit length}=\frac{F}{l}=\frac{\mu_0 I_1 I_2}{2\pi r}$$

Here, $I_1=2\text{A}$

$I_2=3\text{A}$

$r=4\times10^{-2}\text{ m}$

$\therefore$ Force experienced per unit length of the wire $=\dfrac{4\pi\times10^{-7}\times2\times3}{2\pi\times4\times10^{-2}}$ newton/metre

$$=\mathbf{3\times10^{-5}\ N/m.}$$

Example 7.

A long and thin copper foil is hanging as shown in Fig. 8.78 so that its two halves are kept straight and parallel to each other by the weight of a paper tube of 5 mm diameter. If a current of 5 ampere passes through it, find the mutual force per centimetre of their length. Is it repulsive or attractive ?

$$(\mu_0=4\pi\times10^{-7}\text{ Tm/A}).$$

Solution.

We know that,

Force between two wires of length *l* separated by a distance *r* is

$$F=\frac{\mu_0 I_1 I_2 l}{2\pi r}$$

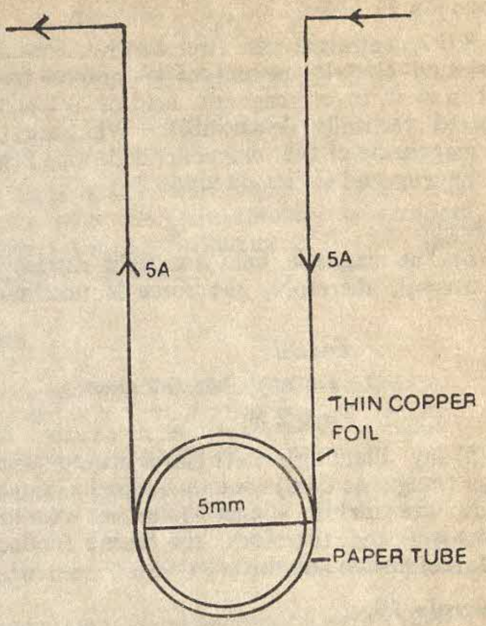


Fig. 8·78

Here, $I_1=I_2=5\text{A}$; $r=5\text{ mm}=5\times10^{-3}\text{ m}$

Let $l=1\text{ m}$

$$\therefore\quad\text{Force per metre}=\frac{4\pi\times10^{-7}\times5\times5}{2\pi\times5\times10^{-3}}$$

$$=10^{-3}\text{ N/m}$$

$\therefore$ Mutual force *per centimetre* of their length $=\dfrac{10^{-3}}{10^2}$ N/m

$$=\mathbf{10^{-5}\ N/cm}$$

Since the currents are in opposite directions in the two halves of the copper foil, the force is one of **repulsion**.

Example 8.

A wire 1 m long is perpendicular to a magnetic field of 5×10^{-2} tesla. What is the force on the wire when it carries a current of 2 amperes ?

Solution.

Here, length of wire $=l=1$ m

magnetic field $=B=5\times10^{-2}$ T

current $=I=2$ A

Since, mechanical force experienced by a conductor carrying current in a magnetic field held at right angles to the field is

$$F=BIl$$

$$\therefore\quad F=(5\times10^{-2})\times2\times1\text{ newton}$$

$$=\mathbf{0{\cdot}1\ N}$$

Example 9.

A 0·2 m straight wire stretched horizontally carries an electric current of 10 ampere from east to west in a magnetic field of 0·1 testla directed vertically downwards. What are (*a*) the magnitude of the magnetic deflecting force on the wire and (*b*) its direction ?

Solution.

(*a*) The magnetic field is at right angles to the current, therefore, the force is maximum and

$$F = BIl$$
$$= (0{\cdot}1) \times 10 \times 0{\cdot}2 \text{ newton}$$
$$= \mathbf{0{\cdot}2\ N}$$

(*b*) By Fleming's Left Hand Rule : First finger (magnetic field) points vertically downwards, the middle finger (electric current) points west and, therefore, the thumb (deflecting force) points **south**.

Example 10.

A moving coil galvanometer has a resistance of 40 ohms and is deflected full-scale with a current of 0·01 ampere through it. How will you convert it into an ammeter measuring upto 10 amperes ?

Solution.

Let a shunt of resistance R_s ohms be connected in *parallel* with the galvanometer of resistance R_g as shown in Fig. 8.79.

The value of the shunt resistance R_s is such that when 0·01 ampere flows through the galvanometer, $(10-0{\cdot}01)=9{\cdot}99$ ampere must pass through the shunt (Fig. 8.79). The potential drop from point *P* to point *Q* is the *same* along resistance R_s or along R_g. This means

$$0{\cdot}01 \times R_g = 9{\cdot}99 \times R_s$$

$$\therefore \quad R_s = \frac{0{\cdot}01}{9{\cdot}99} R_g$$

But $\quad R_g = 40$ ohm

$$\therefore \quad R_s = \frac{0{\cdot}01}{9{\cdot}99} \times 40 \text{ ohm}$$
$$= \mathbf{0{\cdot}04\ ohm}$$

Hence, we can convert this moving coil galvanometer into an ammeter measuring upto 10 A by connecting a shunt of resistance 0·04 ohm *in parallel* with it as shown in (Fig. 8.79).

Example 11.

A galvanometer has a resistance of 20 ohm. A maximum current of 0·50 milliampere can pass through it How will you convert it into a voltmeter measuring upto 5 volts ?

[*A.I.H.S. 1969*]

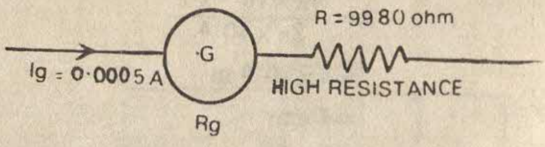


Fig. 8·80.

Solution.

Here, R_g = Resistance of the galvanometer
= 20 ohm

I_g = Maximum current passing through the galvanometer so as to give full-scale deflection
= 0·50 mA = 0·00050 A

According to ohm's Law,
potential difference $= I_g R_g$
$= 0{\cdot}0005 \times 20$ volt
$= 0{\cdot}01$ volt

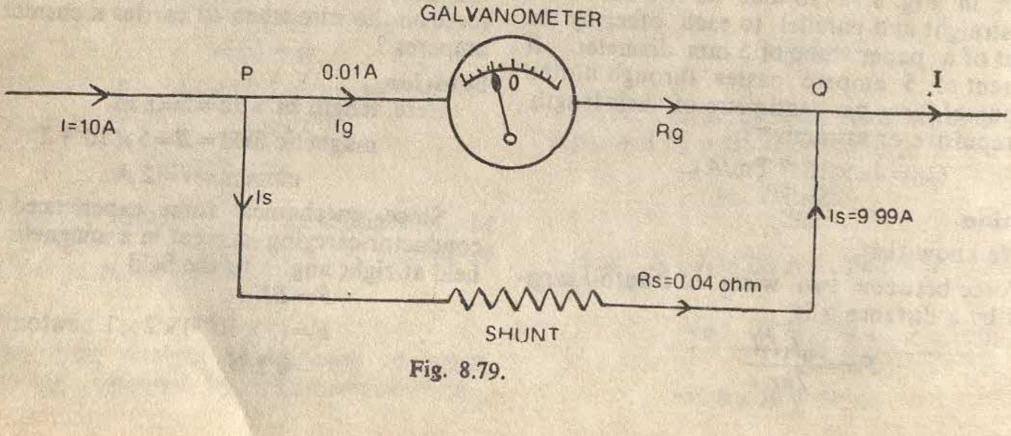


Fig. 8.79.

Such a galvanometer can measure voltage only upto 0·01 volt. In order to convert this galvanometer to measure voltage upto 5 volt, we must add a ***high resistance in series*** with it as shown in Fig. 8.80, such that

$$I_g=\frac{V}{R+R_g}$$

where V = maximum voltage

or $$0{\cdot}0005=\frac{5}{R+20}$$

or $$R+20=\frac{5}{0{\cdot}0005}=10000$$

$$\therefore \quad R=10000-20$$

$$=\mathbf{9980\ ohm.}$$

Thus a high resistance of 9980 ohm *in series* with the galvanometer is required to convert it into a voltmeter of 0—5 V range as shown in Fig. 8.80.

SUMMARY

1. A bar magnet attracts iron fillings more strongly near its free ends. These ends are called the *poles*. If a bar magnet is suspended in such a way that it is free to rotate in a horizontal plane, it takes the north-south direction. The end which points towards the north is called the north pole and the end which points towards the south is called the south pole.
2. Like poles repel and the unlike poles attract each other. The force of attraction or repulsion acts along the line joining the two poles, and is inversely proportional to the square of the distance between them.
3. A magnet can induce similar properties in some substances. We call these ***magnetic substances***. We call this phenomenon *magnetic induction*.
4. If we break a magnet into two or more similar pieces, even the smallest possible magnet has both north and south poles. We cannot obtain isolated magnetic poles.
5. A magnet generates a *magnetic field* in the space surrounding it. The direction of the magnetic field at any point is taken as the direction of the resultant force acting on a hypothetical isolated north pole placed there. A magnetic field is conveniently described by sketching the magnetic lines of force. The magnitude of the magnetic field is proportional to the force experienced by that isolated north pole.
6. Magnetic lines of force have certain characteristics or properties.
7. An infinitely long straight conductor carrying a current (I) produces a magnetic field around it. The ***magnitude*** of the field B produced in vacuum (free space) at a distance r from it is given by

   $$B=\frac{\mu_0 I}{2\pi r} \text{ where } \mu_0=4\pi\times10^{-7}\ Tm/A \text{ is permeability of free space.}$$

   The direction of the magnetic field is given by ***right-hand rule***. It we imagine holding current carrying wire in our right-hand, such that the thumb is stretched along the direction of the current, then the fingers will wrap around in the direction of the magnetic field.
8. S.I. unit of magnetic field is *tesla* (T). It is a fairly big unit. Magnetic field of the earth near the surface is about $0{\cdot}3\times10^{-4}\ T$.

   Magnetic field $\vec{B}$ is a *vector*.
9. ***Force between two long straight, current-carrying conductors :***

   Magnitude : $\frac{F}{l}=\frac{\mu_0 I_1 I_2}{2\pi r}$

   Direction : Attraction if two currents are in same direction ; repulsion if in opposite directions.
10. *Ampere :* That current which, flowing in each of two long parallel wires one metre apart, results in a force between the wires of exactly 2×10^{-7} N per meter of length.
11. ***Magnetic field at the centre of a circular coil carrying current :***

    (*i*) $B=\frac{\mu_0 I}{2r}$

    (*ii*) $B=\frac{n\mu_0 I}{2r}$ where n is the number of turns

12. *Force on a current-carrying conductor of length l in a magnetic field* ·

Magnitude : $F = B_{\perp} I l$ where $B_{\perp}$ is in tesla $(T) = 1 N/(A.m.)$.

Direction : (Fleming's Left Hand Rule). Stretch the first finger, the middle finger and the thumb of your left hand in such a way that they are mutually at right angles to each other. If the first finger represents the direction of the magnetic field, the middle finger represents the direction of the current in the conductor, then, the thumb will represent the direction of motion of the conductor.

13 A solenoid consists of many circular turns of wire wrapped in the shape of a cylinder. Since the current in each circular turn has the same direction, the field due to each turn adds up, giving a fairly strong resultant field inside a solenoid.

In fact, the magnetic field due to a long solenoid has all the properties of the field produced by a bar magnet—the ends of the solenoid acting as the *poles*.

14. Galvanometer is an instrument used for detecting currents flowing in a circuit. Its working is based on the fact that a current-carrying conductor placed in a magnetic field experiences a force perpendicular to both, the current and the field. It is so constructed that the deflection is proportional to the current.

15. *Ammeter* : It is a device which is used for measuring a current in a circuit. It has a very low resistance as compared to the total resistance of the circuit. It is connected *in series* in the circuit as it produces a negligible change in the value of the current.

Ammeter is a modified moving coil galvanometer. It usually consists of a galvanometer with a low resistance *in parallel* with the moving coil. This resistance is called a *shunt*. The value of the shunt resistance depends upon the range of the instrument. The scale is graduated in *amperes* ; with its zero at one end.

16. *Voltmeter* : It is an instrument used for measuring potential difference. It must be placed *in parallel* with the circuit and it must have high resistance.

It is also a modified moving coil galvanometer. The resistance of the galvanometer is increased by putting a *high resistance* in series with its coil. The value of the high resistance depends upon the range of the instrument. The scale is graduated in volts ; with its zero at one end.

17. The phenomenon of production of an electric current in a circuit by the help of the magnetic field is called *electromagnetic induction*. The direction of the induced current is given by *Fleming's right-hand rule* : Stretch the fore finger, the middle finger and the thumb of your right hand in such a way that they are mutually at right angles to each other. If the fore-finger represents the direction of the magnetic field, the thumb represents the direction of motion of the conductor in the magnetic field ; then the middle finger will represent the direction of the induced current in the conductor.

18 An electric generator is a device which converts mechanical energy into electrical energy. A current which changes direction after equal intervals of time is called an *alternating current* (A.C.). A current that flows in the same direction is called a *direct current* (D.C.). A device which produces A.C. is called A.C. generator or an A.C. dynamo. A device which produces D.C. is called D.C. generator or D.C. dynamo.

In India, the A.C. changes direction after every 1/100 second *i.e.* the frequency of A.C. is 50 Hz.

A.C. can be transmitted over long distances without much energy loss.

19. A *transformer* is a device which steps up A.C. voltage or steps down the A.C. voltage. It works on the principle of electromagnetic induction. Since the total power $(P = VI)$ cannot be changed, when we step up the voltage, the current in the circuit is reduced by roughly the same factor.

20. In our homes we receive supply of electric power through mains from electric poles. One of the wires in this supply, usually with red insulation on it, is called *live wire* (or positive). Another wire with black insulation is called *neutral wire* (or negative) Potential difference between them, in India, is 220 volts. At the meter-board in the house these wires go into the watt-hour-meter through a *main-fuse*. Then through a *main switch* they are connected to line wires in the home.

Various appliances in the house are then connected to these line wires, each with its independent switch. In order that each appliance gets equal voltage, *they are connected in parallel with each other*. This also ensures that one is switched 'on' or 'off', other are not affected.

The watt-hour-meter measures the sum total of energy consumed in all the appliances because currents of all the appliances pass through it.

Each pair of live wires carries its own *fuse.*

Now-a-days the main line also carries a third wire (usually with green insulation) which is called *earth wire.* This wire starts from a deep earth connection in the nearest electric sub-station. Importance of this wire is highest for appliance with metallic body. The metallic body is connected to the "earth" wire. Thus even, if there is a mild leakage of current to the body of the appliance, its potential remains equal to that of the earth and we do not receive the electric shock.

21. A *fuse wire* or simply *the fuse* is a wire of low melting point inserted in the positive line wire. It is made from an alloy of tin and lead (Tin 63%+lead 37%).

The thicker the fuse wire, the greater is its capacity. Thus fuse wires of various capacities are available.

22. Earth has a magnetic field which is very similar to the field produced by a huge short bar magnet at its centre—its north pole lying towards the geographical south and south-pole towards the geographical north. The axis of the earth's magnetic field does not coincide with the geographical axis ; the angle between them being about 17°.

Angle of declination is the angle between the magnetic meridian and the geographic meridian at a place. Its value is different at different places on the globe.

If we have a compass needle at a place which can rotate in a vertical plane and we keep it in the magnetic meridian, then the axis of the compass needle will be inclined and the angle which it makes with the horizontal plane is called the *angle of dip* or *the inclination.* At the magnetic poles, the angle of dip is 90°. The line on earth's surface passing through the places having angle of dip 0° is called the *magnetic equator.*

The magnetic field of the earth is quite complex and the elements of the earth's magnetic field (angle of declination, angle of dip or inclination etc.) vary irregularly over the earth's surface and also vary with time.

The general belief is that earth's magnetic field is due to the electric currents circulating in the earth's interior.

QUESTIONS

[A] Objective Type Questions

1. One pole of magnet brought near a piece of iron attracts it. We can be sure that the iron
   (*a*) is a magnet
   (*b*) is magnetic
   (*c*) is electrified
   (*d*) has more than two poles
2. Lines of force produced by a magnet are directed away from the———pole.
3. When the distance between two magnetic poles is increased, the force between them
   (*a*) increases
   (*b*) decreases
   (*c*) remains the same
4. The following electromagnets have the *same* core. Which one is the strongest ?
   (*a*) 100 turns and 3 amperes
   (*b*) 200 turns and 2 amperes
   (*c*) 50 turns and 7 amperes.
5. Electrons are projected perpendicularly into a magnetic field. As the speed with which the electrons are projected increases, the force on the electron
   (*a*) increases
   (*b*) decreases
   (*c*) remains the same

6. Electrons are projected perpendicularly into a magnetic field. As the magnetic field used increases, the force on the electron
   (*a*) increases
   (*b*) decreases
   (*c*) remains the same

7. The magnetic force on a proton moving at right angles to a magnetic field, compared to an electron moving there at the same speed, is
   (*a*) the same
   (*b*) greater
   (*c*) less

8. As the charge on particles projected at a certain speed into magnetic field is increased, the force on the particles
   (*a*) decreases
   (*b*) increases
   (*c*) remains the same

9. Magnetic lines of force are most readily concentrated in
   (*a*) aluminium
   (*b*) iron
   (*c*) silver
   (*d*) gold

10. Permanent magnets are made of
    (*a*) aluminium
    (*b*) copper
    (*c*) alnico
    (*d*) rubber

11. If the N-pole of a compass needle is repelled by the unmarked end of a magnet, that end of the magnet is a———pole.

12. A compass needle is pivoted under a horizontal wire carrying electron current from east to west. The compass needle will point
    (*a*) east
    (*b*) west
    (*c*) north
    (*d*) south

13. Objects lifted by a electromagnet become magnetized by
    (*a*) the current through the objects
    (*b*) induction
    (*c*) the earth
    (*d*) static charge

14. Two parallel wires carry current in the same direction. The magnetic field which they produce midway between them is
    (*a*) zero
    (*b*) not necessarily zero, but less than it would be if the current in one of the wires were zero
    (*c*) greater than it would be if the current in one of them were zero

15. Two parallel wires carry current. If the current in both the wires is *doubled*, the force on one of the wire is

(*a*) doubled
(*b*) quadrupled
(*c*) multiplied by 8
(*d*) multiplied by 16

16. Two parallel wires carry current. If the current in one of them is *doubled*, the force on the *other* wire is

(*a*) doubled
(*b*) quadrupled
(*c*) not affected

17 If an ammeter is to be used to measure the current in a device, it should be connected in———with the device.

18. Two long parallel wires are shown in Fig. 8.81 carrying current in opposite directions.

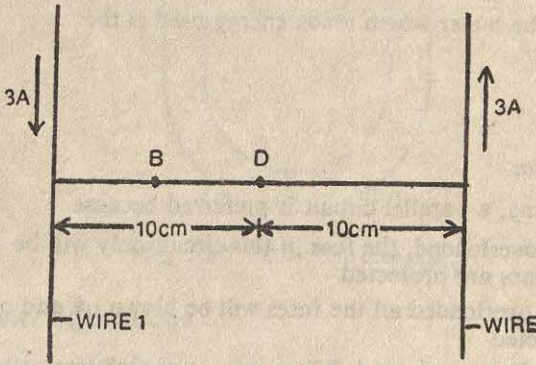


Fig. 8.81.

The direction of the currents is that of electron flow. At point *D* the direction of the resulting magnetic field is

(*a*) into the paper
(*b*) out of the paper
(*c*) towards the top of the paper
(*d*) towards the bottom of the paper
(*e*) none of the above

19. Which of the above nve choices in Q. 18 is correct for point *B* in the diagram ?

20. Which of the choices in Q. 18 are correct for point *C* in the diagram to the left of wire 1 ?

21. If the current in wire 2 in Q. 18 increases a little, the intensity of the magnetic field at *C*.

(*a*) increases
(*b*) decreases
(*c*) remains the same

22. If the current in wire 2 in Q. 18 increases, the force on wire 2
    - (*a*) increases
    - (*b*) decreases
    - (*c*) remains the same

23. As a result of the currents in the two wires in Q. 18, the force on wire 1 as compared with the force on wire 2 is
    - (*a*) greater
    - (*b*) smaller
    - (*c*) numerically the same
    - (*d*) dependent on which wire has the greater current

24. A moving coil galvanometer measures
    - (*a*) charge
    - (*b*) Potential
    - (*c*) strength of current in a circuit
    - (*d*) resistance of a conductor

25. Of the following, the meter which reads energy-used is the
    - (*a*) ammeter
    - (*b*) voltmeter
    - (*c*) ohm-meter
    - (*d*) watt-hour-meter

26. In house hold wiring, a parallel circuit is preferred because
    - (*a*) if one line is overloaded, the fuse in this circuit only will be blown off and other distribution lines are protected
    - (*b*) if one line is overloaded all the fuses will be blown off and other distribution lines are not protected
    - (*c*) there is no uniform potential difference across each line

27. In electrical terminology, *earthing* is a conductor connected
    - (*a*) to the earth
    - (*b*) to an insulator
    - (*c*) to a tree
    - (*d*) None of these

28. A safety fuse must be connected in series with
    - (*a*) live wire
    - (*b*) earth wire
    - (*c*) neutral wire

29. Complete the following
    - (*i*) The magnetic field is largest where the field lines are.........
    - (*ii*) If a positive charge experiences a magnetic force straight up, a negative charge moving in the same direction will experience a magnetic force... .....
    - (*iii*) The magnetic force on a current-carrying wire is zero when the magnetic field is.........or ....to the current
    - (*iv*) In a galvanometer, the deflection is proportional to the.........and.........
    - (*v*) A nearly uniform magnetic field can be found inside a.........
    - (*vi*) The field due to a long straight wire varies.........with the distance.

30. Fig. 8.82 is a diagram of the magnetic field of a horse-shoe magnet. Mark in it poles.

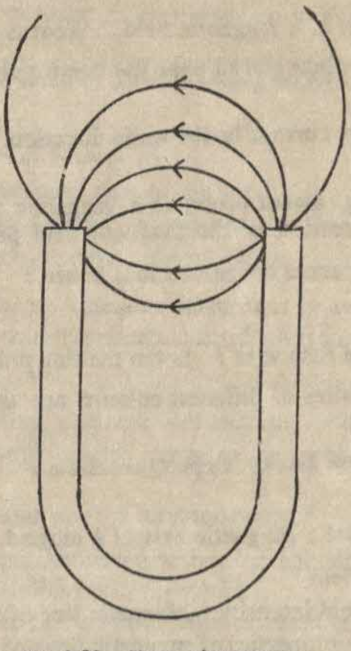


Fig. 8.82. Horse-shoe magnet.

[B] Very Short Answer Questions :

1. What is a magnetic substance ?
2. What is a magnetized substance ?
3. Can a magnet have an isolated pole ?
4. Where can we find a magnetic field ?
5. If we represent a magnetic field by lines of force, how do we differentiate between a strong and a weak field ?
6. When a straight wire carries current, what is the shape of the magnetic field that is produced by the current ?
7. How can the direction of the magnetic field in Q. 6 be determined ?
8. If a circular wire loop carries current, why is there a relatively strong magnetic field in the centre of the loop ?
9. How can we find the north pole of a solenoid if we know the direction of current flow in it ?
10. What determines the strength of a solenoid ?
11. Under what conditions does an electric charge produce a magnetic field ?
12. Does a spinning electron behave like a magnet ?
13. What is a moving coil galvanometer ?
14. What is an ammeter ?

15. What is a voltmeter ?

16. What is an electric generator ?

17. A charge is lying at rest in a magnetic field. What is the force experienced by it ?

18. Will a compass needle when placed near the north pole of a magnet experience a force ? Why ?

19. Two parallel wires carry current in the same direction. Will they attract or repel each other ?

20. A straight wire carrying current produces a magnetic field around it. State the rule which determine the direction of the magnetic field produced.

21. How are electrical appliances connected in a house ?

22. What is earthing ?

23. What is the material of a fuse wire ? Is the melting point of a fuse wire low or high ?

24. Usually three insulated wires of different colours are used in an electrical appliance. Name the three colours. *[A.I.S.S. 1987]*

[C] Short Answer Type and Essay Type Questions :

1. (*a*) What is a magnet ?
   (*b*) Define : pole a magnet ; Magnetic axis of a magnet.

2. (*a*) What is a magnetic field ?
   (*b*) Define : Magnetic field intensity ; Magnetic line of force ; tesla.
   (*c*) Mention some of the properties of magnetic lines of force.
   (*d*) Can two lines of magnetic force intersect with each other ? *[A.I.S.S. 1987]*

3. (*a*) What is a natural point ? (*b*) Can a magnetic field be seen ?
   (*c*) Can it be detected ? (*d*) Can a magnetic field be mapped out ?

4. Draw a magnetic field pattern
   (*i*) around a bar magnet with two poles,
   (*ii*) when a bar magnet is positioned with its north pole towards the magnetic north pole of the earth.
   (*iii*) when a bar magnet is positioned with its north pole towards the magnetic south pole of the earth.
   (*iv*) due to the earth's magnetism at a place.

5. Show by a simple experiment that when current flows inside a wire, a magnetic effect is noticed near it. Mention some rule to determine the direction of the field.

6. (*a*) Discuss the field pattern due to
   (*i*) straight current-carrying wire
   (*ii*) a circular coil carrying current
   and (*iii*) a solenoid

   Draw clear diagrams to explain the chief features of the magnetic fields. (*A.I.S.S. 1982*)
   (*b*) Explain right hand rule to determine the direction of the field in each case discussed in (*a*).

7. What is a Solenoid ? How will you show that a solenoid carrying current behaves like a bar magnet ? Describe the rule for determining the polarity of the ends of the solenoid.

8. (*a*) What is an electromagnet ?

(*b*) Draw a diagram of an electromagnet. Explain how it works.

(*c*) Give a brief account of some of the important practical applications of an electromagnet.

9. We can increase the lifting force of an electromagnet by :

(*i*) increasing the current ;

(*ii*) increasing the number of turn of wire ;

(*iii*) increasing the cross-sectional area of the core ;

(*iv*) making the core of glass instead of soft-iron.

Choose one answer from above which is not correct.

10. (*a*) State Fleming's Left hand Rule and illustrate it by two examples. (*A.I.S.S. 1982*)

(*b*) How can you demonstrate Fleming's Left Hand Rule experimentally ?

11. (*a*) What is a galvanometer ?

(*b*) Describe the construction, principle and working of a moving coil galvanometer.

(*c*) Why is a soft iron cylinder placed between the poles of the magnet in a moving coil galvanometer ?

(*d*) What is a *radial field* and what is its importance ?

12. The magnetic field at a point associated with a current carrying conductor is

(*i*) directly proportional to the current flowing ;

(*ii*) directly proportional to the distance from the conductor :

(*iii*) inversely proportional to the current flowing ;

Choose the correct answer.

13. (*a*) What do you know of the action of magnetic field on a conductor carrying a current ?

(*b*) A wire *BA* of length *l* (Fig. 8.83) is placed vertically between the poles of a large magnet having magnetic field *B* tesla. It is free to turn in any direction. State and explain what happens when a current *I* is passed through the wire in the direction *AB*. (A is free to move).

What is the expression for the mechanical force experienced by the wire carrying current ?

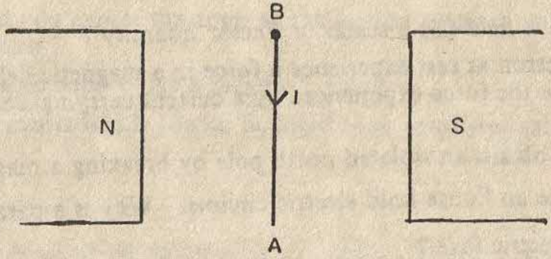


Fig. 8.83.

14. If the direction of a current in a conductor is towards the reader but out of the pages, is the direction of magnetic field (*Choose one answer*)

(*i*) along the conductor towards the reader ?

(*ii*) clockwise around the conductor ?

(*iii*) counter-clockwise around the conductor ?

(*iv*) along the wire into the page.

15. A straight conductor is placed parallel to the magnetic field of a magnet. Will it move in any direction when a current is passed in it ? Give your reasons.

16. (*a*) Give the unit of magnetic field in SI system and define it.

(*b*) How tesla and gauss are related to each other ?

17. (*a*) What is a galvanometer ?

(*b*) Copy Fig. 8.84 and put in an arrow showing which way the coil (free to turn about a vertical axis) tends to move.

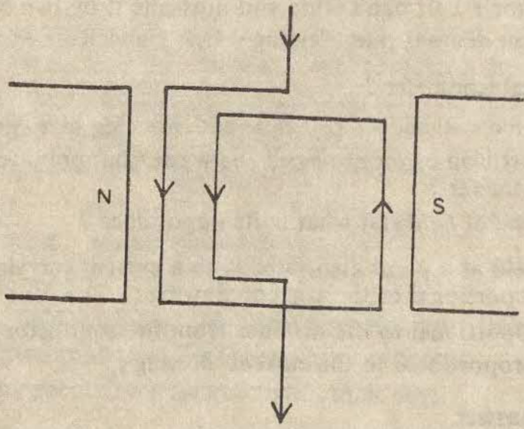


Fig. 8.84

18. (*a*) Two parallel wires carry current in the same direction. Describe the forces on each of them. What if the currents are in opposite directions ?

(*b*) Calculate the force between two infinitely long straight conductors carrying current and hence define ampere. [*A.I.S.S. 1987*]

19. (*a*) What is magnetic field (B) ?

(*b*) Does a small magnetic needle experience a force when placed in the magnetic field of another magnet ?

(*c*) Is the magnetic field (B) a scalar or Vector quantity ?

(*d*) Does an electron at rest experience a force in a magnetic field ? Name two factors that influence the force experienced by a current carrying conductor in a magnetic field.

20. Why cannot one obtain an isolated north pole by breaking a magnet into two pieces ?

21. Write a short note an house hold electric circiuts. Why is a parallel circuit preferred ?

22. (*a*) What is an electric fuse ?

(*b*) Why does fuse contain tin and lead ?

(*c*) Outline how you would demonstrate the action of a fuse wire in a circuit.

(*d*) Why is it dangerous to replace a fuse with an iron nail ?

(*e*) In what way do electric fuses serve as a safety device in electric circuits ?

23. (*a*) What is meant by earthing of electrical appliances ?

(*b*) In What ways does earthing serve as a safety device in electrical appliances ? Explain with the help of an example.

24. (*a*) Under what conditions is an induced emf produced ?

(*b*) When does an induced emf produce an induced current ?

(*c*) What are the factors which affect the magnitude of an induced emf ?

25. What are magnetic lines force ? How is the direction of a magnetic field at a place determined ?

Mention the important properties of the magnetic lines of force.

26. How do you interpret the following patterns of magnetic lines of force ?

(*a*) The lines of force are parallel to each other.

(*b*) The lines of force come closer to each other as we proceed in the direction indicated by north pole of a small compass.

(*c*) The lines of force get further apart from each other as we proceed in the direction indicated by north pole of a small compass

27. How can you demonstrate experimentally that a straight conductor carrying current placed in a magnetic field experiences magnetic force ? Define magnetic field strength and give its unit.

28. (*a*) What is an electric generator ? Draw a labelled diagram of an A.C. generator.

(*b*) What are the important parts of an A.C. generator ?

What is the function of each of these parts ?

(*c*) Why is energy required to rotate the armature of a generator ?

(*d*) Why does the direction of the induced current in the coil change after every half revolution

[*A.I.S.S. 1987*]

29. What is the essential difference between

(*a*) alternating current (A.C.) and direct current (D.C.) and (*b*) A.C generator and D.C. generator.

What is the frequency of A.C. in India ?

30. Define (by drawing diagrams) :

(*a*) Magnetic meridian

(*b*) Angle of declination

(*c*) Angle of dip or (inclination)

(*b*) How would you expect the angle of inclination to alter on a journey from London to Cape Town ?

(*c*) Does the earth behave like a magnet ? Explain.

31. State the attachments which should be fitted to a sensitive galvanometer to convert it for use as

(*a*) a voltmeter

(*b*) an ammeter.

Draw diagrams to show the method of connection of these attachments.

32. (*a*) Draw a diagram to show the production and detection of a current induced in a coil of wire by means of a magnet. State briefly what is to be observed and show clearly on your diagram the direction of the induced current if the north pole of the magnet is approaching the coil.

(b) State the factors on which the magnitude of the induced current depends, and the source of the electrical energy obtained.

(c) What is this phenomenon called ?

(d) State the rule which determines the direction of induced current ?

(e) Give reason for the generation of induced current.

33. (a) Draw a diagram to illustrate the essential features of a transformer connected to a 200-volt main and lighting a 50-volt lamp.

(b) State the type of transformer (step-up or step-down)

(c) State the type of electric main (a.c. or d.c.)

34. (a) How can one locate a concealed current-carrying conductor ?

(b) How will you connect a table lamp to the mains plug so that the cable connecting the plug to the lamp produces little or no magnetic field ?

35. State the rule for the direction of a :

(a) magnetic field produced around a current-carrying conductor ;

(b) force experienced by straight conductor, carrying current placed in magnetic field ;

(c) current induced in a straight conductor, cutting the magnetic lines of force.

36. On what factors does the force experienced by a current-carrying conductor placed in a uniform magnetic field depend ?

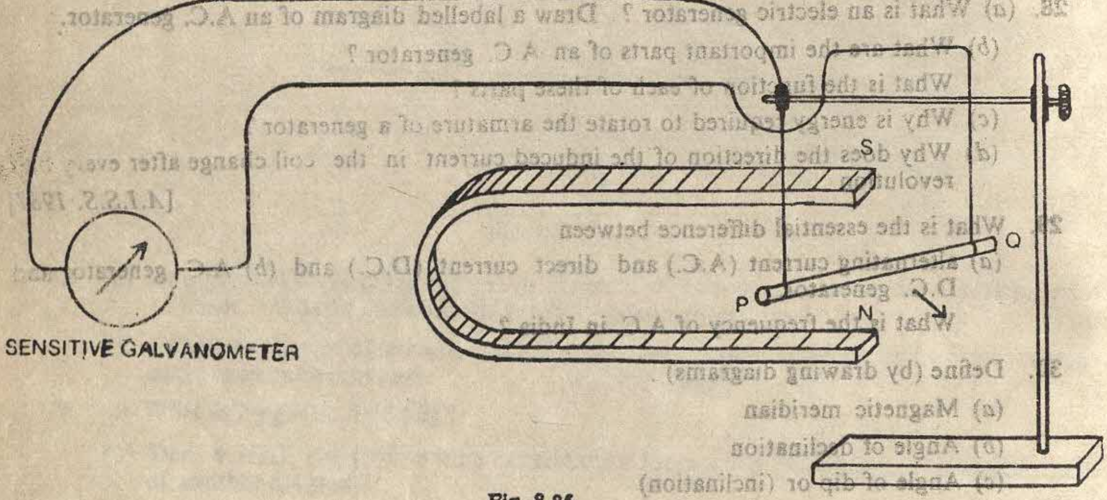


Fig. 8.85

37. Consider the apparatus shown in Fig. 8·85. As the rod *PQ* moves in the magnetic field from the right find by Fleming's left-hand rule, the direction in which force will be experienced by the negative charges within the rod. What will be the direction of induced current produced by this force ? Is this direction of induced current according to Fleming's right-hand rule.

[**Hints :** Force on negative charges along *PQ*. Induced current in direction *QP* ; yes]

38. What is an electromagnetic induction ? Describe an experiment to demonstrate this phenomenon.

39. The *S*-pole of a horse-shoe magnet rests on the table, with the *N*-pole vertically above it. A beam of alpha particles moves from left to right through the space between the poles. Apply Fleming's Rule to get the direction of deflection of alpha particles.

[*A.I.S S. 1987*]

PROBLEMS

1. Calculate the magnetic field at the centre of a circular wire of radius 10 cm, carrying a current of 2A. How much is the field, if the number of turns in the coil is 100? $\mu_0=4\pi\times10^{-7}$ Tm/A. [**Ans.** $12{\cdot}57\times10^{-6}$ T ; $12{\cdot}57\times10^{-4}$ T]

2. Two long parallel wires carrying the same current of 2A are at a distance of 1 cm from each other. What is the mutual force per metre of their length? $\mu_0=4\pi\times10^{-7}$ Tm/A. [**Ans.** 8×10^{-5} N]

3. What is the magnetic field at a distance of 100 mm in air from a long straight conductor carrying a current of 6·5 A? Hence calculate the force per metre on a similar parallel conductor 100 mm distant from the first and carrying a current of 3·0 A. $\mu_0=4\pi\times10^{-7}$ Tm/A. [**Ans.** 13×10^{-6} T ; $3{\cdot}9\times10^{-5}$ Nm^{-1}]

4. In the situation shown in Fig. 8·86, the length L of the wire PQ is 10 cm, the current I is 5·0 A, and the magnetic field B has a strength of 0·50 T in the direction shown.

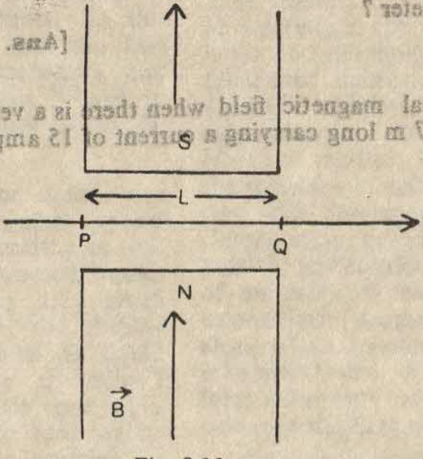


Fig. 8.86

(*a*) What is the magnitude of the force of the wire?

(*b*) What is its direction? [**Ans.** (*a*) 0·25 N (*b*) Out of plane of paper]

5. Two long parallel wires are 10·0 cm apart and carry current of 2·0 A and 5·0 A in the same direction. Find the magnitude of the force between the wires. Is it force of repulsion or force of attraction? $\mu_0=4\pi\times10^{-7}$ Tm/A. [**Ans.** 2×10^{-5} Nm^{-1} ; attraction]

6. A 0·5m long segment of a wire carrying a 2×10^{7} μA current experiences a force of 5N when it is perpendicular to a magnetic field. What is the magnitude of the field? [**Ans.** 0·5 T]

7. A circular current loop of radius 0·2 m has a resistance of 100 ohms and is connected to a 12V battery. What is the magnetic field at the centre of the loop? $\mu_0=4\pi\times10^{-7}$ Tm/A. [**Ans.** $3{\cdot}77\times10^{-7}$ T]

8. The magnetic field due to a current pulse in a single long, straight axon (nerve fiber) is found to be $1{\cdot}2\times10^{-10}$ T at a distance of 1·3 mm from the axon. How large is the current in the axon? $\mu_0=4\pi\times10^{-7}$ Tm/A. [**Ans.** $7{\cdot}80\times10^{-7}$ A]

9. Two parallel wires attract each other with a force of 10^{-4} Nm^{-1} of length. The wires are 0·01 m apart. The current in one wire is 20A. What is the magnitude and relative direction of the current in the other wire ? ($\mu_0 = 4\pi \times 10^{-7}$ Tm/A).

[Ans. 0·25 A ; parallel]

10. A wire carrying a current of 5 ampere perpendicular to a magnetic field of 1T experiences a force of 1N. What is the length of the wire ? [Ans. 0·20 m]

11. A current of 1mA is passed through a straight wire of length 2 cm in a uniform perpendicular magnetic field of 18 tesla. What is the magnetic force on the wire ? What will be the force when wire is placed parallel to the field ?

[Ans. 36×10^{-5} N ; zero]

12. A certain galvanometer has a resistance of 40 ohms and deflects full scale for a voltage of 100 millivolts across its terminals. How can it be made into a 2-ampere ammeter ?

[Ans. Use a shunt of 0·050 ohm]

13. If a galvanometer deflects full scale to a current of 0·010 ampere and has a resistance of 50 ohms, how can it be made into

(*a*) a 5—A ammeter ?

(*b*) a 20 volt voltmeter ?

[Ans. (*a*) Use of shunt of 0·1 ohm
(*b*) Place 1050 ohms in series]

14. Find the horizontal magnetic field when there is a vertical force of $3{\cdot}3 \times 10^{-8}$ N on a horizontal wire 0·67 m long carrying a current of 15 ampere. [Ans. $3{\cdot}3 \times 10^{-4}$ tesla]

CHAPTER 9

Atomic Structure of Matter

9.1. INTRODUCTION

The world around us is made up of matter in a great variety of forms—solids, liquids, gases. To understand the structure of matter, we must first understand the building blocks out of which all matter is constructed, *i.e.*, the particles which make up atoms and molecules and hence matter in all its forms. In this chapter, we will consider the particles that combine to form atoms and molecules, and how these atoms and molecules behave to produce the observed properties of solids, liquids and gases.

If one looks at things in some detail, one may get confused. For example, glass appears to be a solid but if we ask a scientist, he will tell us that it is really a supercooled liquid. If we have had a chance to look at a small calculator or an electronic watch, the display is often made of materials known as liquid crystals. How can a liquid be crystalline? Thus to identify correctly the true state of a given material, it is not enough to look at its gross properties but we must examine its structure at the atomic level (micro level).

Atomic energy has become a household name in the modern world. As the human progress (including economic development) depends on the use of the energy, it is thus very important for the student to know about the structure of atoms. Radioactive elements have various useful applications as well as harmful effects and so it is right to give the idea of radioactive substances in this chapter.

9.2. GRANULAR STRUCTURE OF MATTER

Nature has built up the material universe around us by combining a small number of elementary particles into a multitude of ingenious physical structures which we call *atoms* and *molecules*. All matter consists of a few elements. Each element has its characteristic atoms. There are as many kinds of atoms as there elements. Atoms of a given element are identical in all respects. Some elements can combine to form a compound, the smallest unit of which is called a molecule. Molecules of a given compound are identical in all respects. If enough energy is supplied to a molecule, the bonds between atoms can break and the molecule dissociates. In nature, there exist molecules which are composed of thousand of atoms *e.g.* polymers and biological molecules. Molecules are the ***building blocks*** of matter. Thus, at the atomic level, the structure of matter appears to be ***granular***, *i e*, with free space between atoms. Even though atoms are of extremely small size, it is possible to determine their sizes. The diameter of an atom is only about 10^{-10} m, which means that if atoms were placed side by side along a line touching one another, it would take about one hundred million of them to form a line only one centimeter long. Molecules are still large in size.

An atom is too small to be seen directly, even with a microscope. For example, consider a drop of pure water a few millimetres in size. On looking at it even with a magnifying lens, we will see a continuous liquid. If we look at it through a microscope which magnifies the drop about a thousand times, we will still find no change in the appearance of water. If we could magnify the drop about a million times more, we would then begin to see that water is no longer continuous but consist of particles, which we call molecules. Hydrogen and oxygen combine to form water. Hydrogen is a chemical element and is therefore composed of atoms that are all of the same kind and are called hydrogen atoms. Actually hydrogen atoms join together in pairs to form hydrogen molecules. Oxygen is also a chemical element and its molecule is composed of two oxygen atoms that are different in many

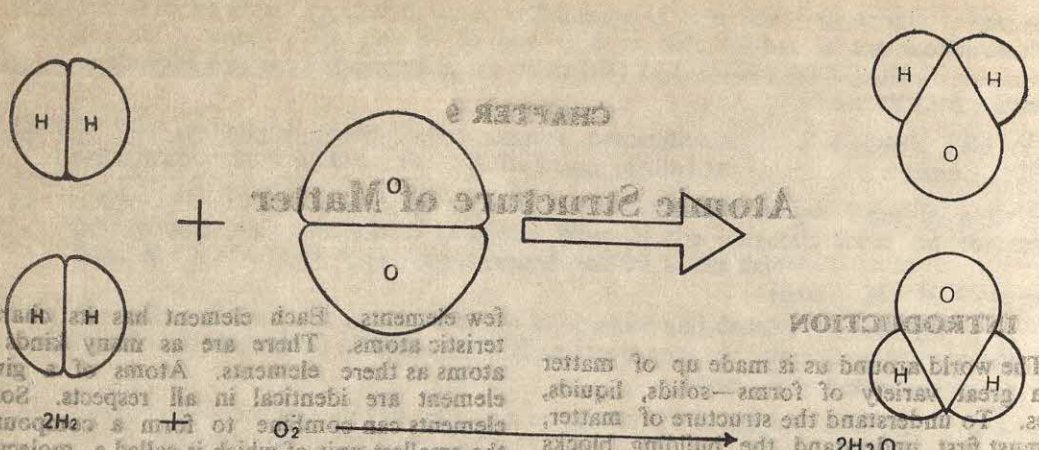


Fig. 9.1.

respects from hydrogen atoms. When hydrogen and oxygen react chemically, two hydrogen molecules come together with one oxygen molecule and the atoms are reshuffled to form two water molecules, each of which contains one oxygen atom and two hydrogen atoms (Fig. 9.1).

X-rays are similar to light. It is, therefore, possible to design an X-ray microscope which will reveal the structure of the atom. It is still not possible to see an individual atom, but if the X-rays are scattered by an orderly array of atoms in a solid, it is possible to deduce from the detailed nature of the scattering the spatial arrangement of the atoms in the solid.

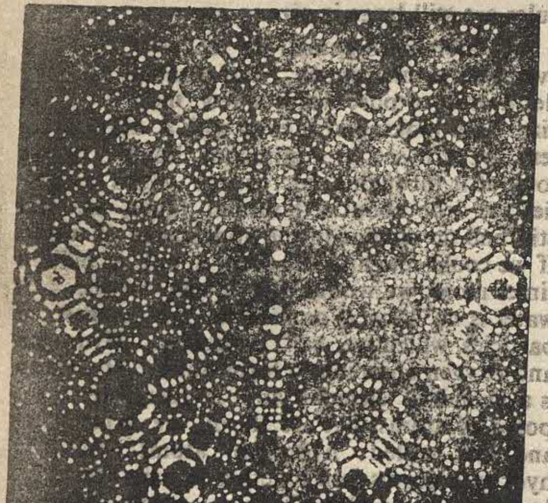


Fig. 9.2.

One of the impressive ways of "seeing" atoms the *field ion microscope* invented by E.W. Muller. A photograph of atoms on the surface of a metal tip (tungsten) is shown in Fig. 9.2.

9.3. ATOMS ARE IN CONSTANT MOTION

The molecules of a substance are in constant motion. They are continually moving turning and twisting around. This random motion of the molecule is because of thermal energy of matter. The amount of motion depends upon the average kinetic energy of the molecules and this energy depends upon the temperature.

The atoms do not have sharp boundaries. They attract each other at small distances and yet do not squeeze each other. If we push them together too close, they even repel. Because of this repulsion at very short, separations and attraction at the large distances, the atoms attain equilibrium at some well-defined distance of separation. Thus different molecules have different sizes and shapes.

When we heat water, we increase the agitational motion of the molecule. This leads to an increase in its volume. When the energy of the particles increases beyond a certain limit, they can no longer be held bound in the liquid and begin to fly apart. This is how we get water vapour or steam. Now when we have steam (or any other gas) in a container, the molecules strike against the walls of the container giving them a certain push. Though the push given by individual molecule is extremely small, their number is so large that total push becomes significant. We refer to it as the pressure of the gas. Clearly if we increase the temperature of a given gas, we increase the energy of the constituent particles. These would then hit the walls harder and also more frequently and so the pressure would, increase. Similarly, at a given volume and temperature *i.e.*, for the same energy of the molecules when we increase the number of the molecules, there will be more collisions with the walls and so the pressure would again rise. Thus the pressure, for a given temperature, also increases with increase in the density of the gas.

Let us now consider what happens when we start decreasing the temperature of a drop of water. The energy of the molecules would start decreasing. When the temperature gets very low, the motion of the molecules becomes very slow and the binding between molecules becomes important. They get almost fixed in certain locations. This leads to the formation of a crystalline solid.

The above example illustrates the main differences between solid, liquid and gaseous states of a substance on the basis of the atomic model. In a solid, the particles are arranged in some order and have their relative positions almost fixed so that on applying a small force, it does not change its size or shape. The phase molecules vibrate about the equilibrium position and they do not have enough energy to overcome the attractive force. In a liquid, the particles are held together but thermal agitation dominates and molecules no longer occupy fixed positions. They move around at random and a liquid takes the shape of the vessel which holds it. In the gaseous state, the bonds between the molecules are broken and they fly about in all directions. If enclosed in a vessel, a gas occupies all available volume. The average distance of separation between the gas molecules is considerably greater than the range of intermolecular forces and the molecules move in straight lines between collisions.

The above description serves to illustrate how the simple atomic concept of matter helps us to understand the various physical properties of substances around us.

9.4. STRUCTURE OF ATOMS

In the past few decades experimental physists have discovered a whole 'zoo' of elementary particles, many of which are not understood even to-day. Fortunately for us only three of these many particles are needed to understand the basic structure and behaviour of atoms and molecules. These three are the *electron*, the *proton* and the *neutron*.

The electron is a particle of very small mass, $9{\cdot}11 \times 10^{-31}$ kg, which carries the electric current in the wires leading to the our electric toasters and TV sets. It has a negative electric charge of $1{\cdot}60 \times 10^{-19}$ coulomb *(C)*, and it is this charge which gives the electron its unique importance in practical electric and electronic circuits.

The proton has a mass 1836 times that of the electron, or $1{\cdot}673 \times 10^{-27}$ kg still a small mass on any ordinary scale. The proton's charge is positive, and is *exactly equal* in magnitude to the charge on the electron. The radius of a proton is believed to be about $0{\cdot}8 \times 10^{-15}$ m.

The neutron has *no charge*, and is therefore electrically neutral. Its mass is $1{\cdot}675 \times 10^{-27}$ kg which is close to that of the proton, but about 0·14 percent larger. Data for these building blocks of atoms are given in Table 9.1.

TABLE 9.1. Properties of the Particles in Atoms

Particle	*Symbol*	*Charge (C)*	*Mass (kg)*
Electron	*e*	$-1{\cdot}60219 \times 10^{-19}$	$9{\cdot}11 \times 10^{-31}$
Neucleons :			
Proton	*p*	$+1{\cdot}60219 \times 10^{-19}$	$1{\cdot}67265 \times 10^{-27}$
Neutron	*n*	0	$1{\cdot}67495 \times 10^{-27}$

The three elementary particles—the positively charged proton, the negatively charged electron, and the uncharged neutron—are the basic building blocks out of which all atoms both great and small, are constructed. Owing to the experimental work of Prof. Ernest Rutherford at Manchester in England in 1911, we now know that every atom has a *nucleus* or *central core*, which contains all the protons and neutrons as shown in Fig. 9.3. It is common practice to refer to the protons and neutrons in the nucleus collectively as **nucleons**. Since the electrons are so light, the mass of the atom is basically the sum of the masses of the neutrons and protons in the nucleus. The nuclear charge is positive and numerically equal to the sum of the charges on the protons in the nucleus.

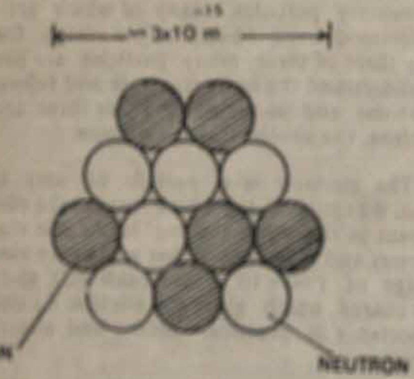


Fig. 9.3.

The nucleus is extremely small. Its size is estimated to be about 10^{-15} m (=1 fermi=1 fm) and is therefore extremely dense. The density of matter inside the nucleus is about $2{\cdot}3\times10^{14}$ times greater than the density of water. Since it was well known even in Rutherford's time that the diameter of atoms, as computed from the density of crystals, was about 10^{-10} m (=1 A°), it is clear that atoms contain a great deal of empty space. If one wanted to see the nucleus of an atom, one would have to magnify the atom almost 10^{11} times, so that it had a diameter of about 10^{-4} m. Then the nucleus would appear just as a small dot. If atom were magnified to the size of Mount Everest, the nucleus would still be only about as large as a football.

The region of the atom outside the nucleus contains a number of electrons equal to the number of protons in the nucleus. This makes the overall atom electrically neutral, since the positive charges in the nucleus just cancel the negative charges on the electrons. These electrons are in rapid motion in the space surrounding the nucleus. It is impossible to say where any electron is at any precise instant of time, but quantum mechanics shows that it is possible to specify the regions of the atoms in which the electron is most likely to be found. Despite this inherent ambiguity as to the position of the electrons, diagrams of atoms often show the electrons moving in precise circular or elliptical orbits about the nucleus. This is the way electrons were originally pictured in the atom described by Rutherford and Niels Bohr, and for some purposes this concrete picture is still useful today. Fig. 9.4 shows a model of a carbon atom drawn in this approximate way.

Since an atom is usually electrically neutral, the number of positively charged protons in its nucleus must equal the number of negatively charged electrons moving around the nucleus. The *Z*th element in the periodic table has *Z* electrons and therefore has *Z* protons in its nucleus. *Z* is called the **atomic number** or *charge number* of the atom. This number is 1 for hydrogen, 2 for helium, 92 for uranium and it distinguishes the atoms of one chemical element from those of all other elements, and accounts for most of the significant physical and chemical properties of the atom. If there are also *N* neutrons in the nucleus the total number of protons and neutrons is

$$A=Z+N$$

A is called the **mass number**. It is an exact integer. If the chemical symbol for an

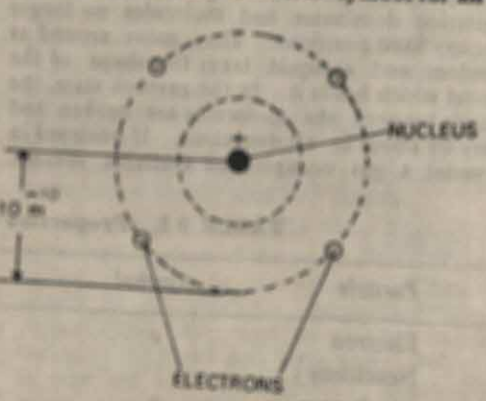


Fig. 9.4.

element is X, it is customary to denote its nucleus by ${}^{A}_{Z}X$. The subscript in front of the chemical symbol gives the number of protons and the superscript following it gives the total number of nucleons (protons and neutrons). For example, ${}^{7}_{3}Li$—lithium has 3 protons and 7−3=4 neutrons in the nucleus. For a given atomic number, one can have nuclei with different mass numbers and these are called *isotopes*. Since the chemical properties of an atom depend on its atomic number, the various isotopes of an element are chemically indistinguishable.

In some ways, the structure of an atom is similar to that of our solar system. Just as the planets revolve round the sun, the electrons revolve round the nucleus. Most of our solar system is empty space, and so also an atom. But here the analogy stops. For one thing it is the gravitational force which binds the planet's to the sun, here it is the coulomb force which binds the electrons to the nucleus. However, the major difference lies in another fact. Whereas a planet can, in principle, revolve round the sun in any orbit and have any value of energy (*i.e.* the energy can vary continuously), in an atom electrons can move only in certain well-defined orbits and are permitted to have only certain discrete energy values. We denote these energy values by E_0, E_1, E_2, E_3, ... E_{n-1}, E_n where E_0 is the lowest allowed energy and the other energy values are arranged is an ascending order, *i.e.*, E_1 E_2 E_3 ... E_n as shown in Fig 9.5. These values will obviously depend upon the element we are considering. For example, for hydrogen atom $E_0=0$, $E_1=16{\cdot}31 \times 10^{-19}$ J and this atom gets ionised* by an energy of 21.76×10^{-19} J.

An electron in an atom cannot move continuously from one orbit (or one *energy state*) to another orbit (or another energy state). Rather, it jumps from one energy state to another and in so doing it absorbs or releases energy in the form of a **bundle** or **quantum** of light.

Let us consider the simplest of the atoms, the hydrogen atom (Fig. 9.6). Its nucleus consists of a single proton, and one electron revolves around it. Normally the electron will be in the lowest allowed energy state, E_0. The electron can 'jump' from this lowest allowed energy state E_0 to any one of the allowed higher energy states, say E_n by absorbing a light quantum of just the right energy, $(E_n - E_0)$. On the other hand when the electron jumps from higher energy state, E_n to a lower energy state, say E_m, $(E_n > E_m)$, then a light quantum of energy $(E_n - E_m)$ is emitted.

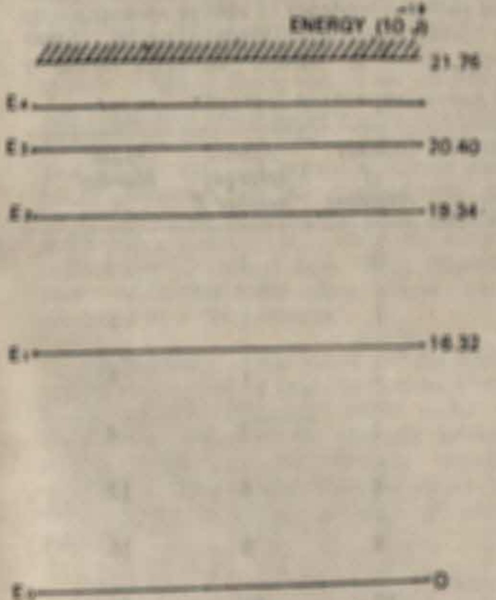


Fig. 9.5. Energy levels of hydrogen atom

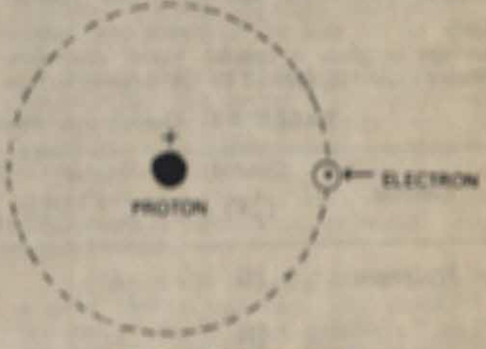


Fig. 9.6. Hydrogen atom

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*If an electron is removed from a neutral atom, the atom ceases to be electrically neutral and takes on a positive charge. Such an atom is called a positive ion. If it gains an electron, it is called a negative ion.

9.5. ISOTOPES

Two atoms may have the same number of protons and electrons but have different number of neutrons in the nucleus. Such atoms are distinguished by their mass number A, written as a superscript before the chemical symbol, and are called *isotopes*. Thus isotopes are atoms having the same atomic number Z, but different mass numbers A.

The word isotope comes from the Greek words meaning the "same place", which appropriately applies to position in the periodic table. Isotopes of the same atom usually have the same chemical properties, since these depend upon the electrons, but their nuclear properties may differ greatly.

Hydrogen has two prominent isotopes which we specify as ^1_1H and $^2_1H = ^2_1D$. These differ in the fact that the heavier isotope ^2_1H (or ^2_1D) has a proton and a neutron inside the nucleus whereas ^1_1H has only one proton. Only in the case of hydrogen the heavier isotope is given a special name, *deuterium*. Water molecule, formed by the heavier isotope combining with oxygen, is chemically written as D_2O and is called *heavy water*. Another important example of isotopes is that of the two isotopes of uranium ; $^{235}_{92}U$ and $^{238}_{92}U$. Both have 92 protons and 92 electrons. The first has $235-92=143$ neutrons in the nucleus, while the second has $238-92=146$. Their chemical and physical properties, as found from chemical reactions, spectra, etc. are almost identical, but their nuclear properties are vastly different.

Whereas $^{235}_{92}U$ is a fissionable material useful in nuclear reactors and bombs, $^{238}_{92}U$ is a non-fissionable and relatively useless material as found in nature. Only 0·72% of natural uranium is $^{235}_{92}U$. The number of protons, neutrons, and electrons in some important isotopes are given in Table 9.2.

9.6. RADIOACTIVITY (Unstable Isotopes)

Most elements have nuclei which are stable and show no tendency to change spontaneously or "decay" into other kinds of nuclei. Some nuclei found in nature, however, especially

TABLE 9·2. Constituent Parts of Some Important Isotopes

Element	*Symbol* (^A_ZX)	*Number of Protons*	*Number of Electrons*	*Number of Neutrons*	*Atomic (charge) number Z*	*Mass Number A*
Hydrogen	^1_1H	1	1	0	1	1
	^2_1H	1	1	1	1	2
	^3_1H	1	1	2	1	3
Helium	^4_2He	2	2	2	2	4
Carbon	$^{12}_6C$	6	6	6	6	12
Oxygen	$^{16}_8O$	8	8	8	8	16
Iron	$^{56}_{26}Fe$	26	26	30	26	56
Uranium	$^{235}_{92}U$	92	92	143	92	235
	$^{238}_{92}U$	92	92	146	92	238

those at the large-mass end of the periodic table, are unstable and decay into different nuclei by emitting highly energetic particles. Such nuclei are called **radio-active**. **The phenomenon itself came to be known as radio-activity** or **natural radio-activity,** a name given by the Polish-French physicist Marie Curie in 1898. For example, polonium, actinium, uranium, radium, thorium etc. exhibit this phenomenon.

The first evidence for natural radio-activity was found by the French Physicist Antoine Henri Becquerel (1858-1908) in 1896, when he discovered that a chemical compound containing the element uranium was able to expose photographic film placed near it in a drawer, even though the film was tightly wrapped in black paper. Bequerel rightly gussed that some atoms in the uranium compound were emitting particles of sufficient energy to penetrate the wrapping paper and expose the photographic film. It was soon established that uranium atoms were the culprits. A few years later Marie Curie and her husband, Pierre Curie (1859—1906) were able to extract, using laborious chemical techniques, small quantities of the new elements polonium ($^{210}_{84}PO$) and radium ($^{226}_{88}Ra$) from tonnes of pitchblende and found that these elements were more highly radio-active than uranium itself. Polonium and radium are two typical naturally radio-active substances. At the present time some 30 natural elements have been found to possess radio-active isotopes, and over 50 naturally radio-active isotopes have been identified. Many additional radio-active isotopes can be produced by artificial means.

Radioactivity is the result of the disintegration or decay of an unstable nucleus. Certain nuclei are not sufficiently stable under the combined operation of the strongly attractive nuclear force and the strongly repulsive coulomb force, and spontaneously decay with the emission of nuclear particles of various kinds.

What kinds of particles are emitted by naturally radio-active nuclei? It is easy to show by a simple experiment that they fall into three distinct classes. In the early days of the study of radio-activity, when the nature of these particles was as yet unclear, Lord Rutherford (1871—1937) differentiated them by the first three letters of the Greek alphabet as **alpha** (α), **beta** (β), and **gamma** (γ) rays.

We now know that the alpha rays are nothing but helium nuclei stripped of their electrons, that is, $^4_2He^{2+}$. These relatively heavy particles rapidly lose their kinetic energy by collisions, they travel on the average only an inch or so in air before they combine with free electrons and become normal helium atoms. They possess a positive charge equal to $3{\cdot}19 \times 10^{-19}$C, which is practically twice that of an electron. They are deflected by the magnetic and electric fields.

Beta (β^-) rays are nothing but ordinary *fast electrons*, which differ from the electrons in the exterior of atoms only in that they are produced in the decay of radio-active nuclei. Beta rays travel only a few metres in air before they are slowed down sufficiently by collisions to combine with positive ions and form neutral atoms. They are easily deflected by the magnetic fields and also by the electric fields. They produce a distinct effect on the skin. They blacken photographic plates. Their emission velocities approach the velocity of light *i.e.*, 3×10^8 ms^{-1}.

Gamma rays are radiations of the same nature as light but having a *very short* wavelength, of the order of 10^{-10} m or less. They penetrate matter readily and are unaffected by magnetic or electric fields. They have no charge and no rest mass. They are the most difficult of all radioactive emissions against which to shield.

A question now naturally arises is whether a given element can have any number of isotopes, *i.e.*, for a given number of protons can one have any number of neutrons inside the nucleus? The answer is no. It is found that in nature only a few isotopes exist for each element. If there is an excess of neutrons or a defficiency over what is normally found in nature the nucleus becomes unstable. It tends to become stable by emitting a charged particle. In the case of neutron-rich isotopes, an electron (beta particle —β^-) is emitted. A positively charged electron (β^+ particle) called *positron* is emitted in the case of neutron-defficient isotopes. Note that neither an electron nor a position exist inside the nucleus. They are created there—an electron by the transformation of a neutron into a proton and a positron by the transformation of a proton into a neutron.

We can never know how long it will take any particular nucleus to decay just as we can never know how long it will take for a particular atom to fall spontaneously to a lower-energy state and emit light. What we can determine experimentally, however, is how long it takes *on the average*, for a large group of radio-active nuclei of the same species to decay to some other species. Suppose, for example, that we have 100 million $^{137}_{55}Cs$ nuclei in a box. If we could go away and return 30 years later, and again count the number of cesium nuclei present, we would find that we had only 50 million left. The other 50 million would have spontaneously transformed themselves into barium nuclei by the following beta—decay

$$^{137}_{55}Cs \rightarrow \beta^- + ^{137}_{56}Ba$$
$$(^{0}_{-1}e)$$

If this is the case, we say that the *half-life* of $^{137}_{55}Cs$ is 30 years.

Thus the **half-life** *of a radio-active sample is the time required for the number of radio-active atoms to drop to half its initial value.* For example, the half-life of $^{238}_{92}U$ is $4{\cdot}5 \times 10^9$ years, whereas for $^{235}_{92}U$ it is $0{\cdot}17 \times 10^9$ years. This explains why $^{235}_{92}U$ occurs in such a small proportion in the natural uranium. The half-life of radio-active atoms varies considerably—ranging from billions of years to a fraction of a second. For example, $^{14}_{6}C$ which is a β-emitter and transforms to $^{14}_{7}N$ has a half-life of

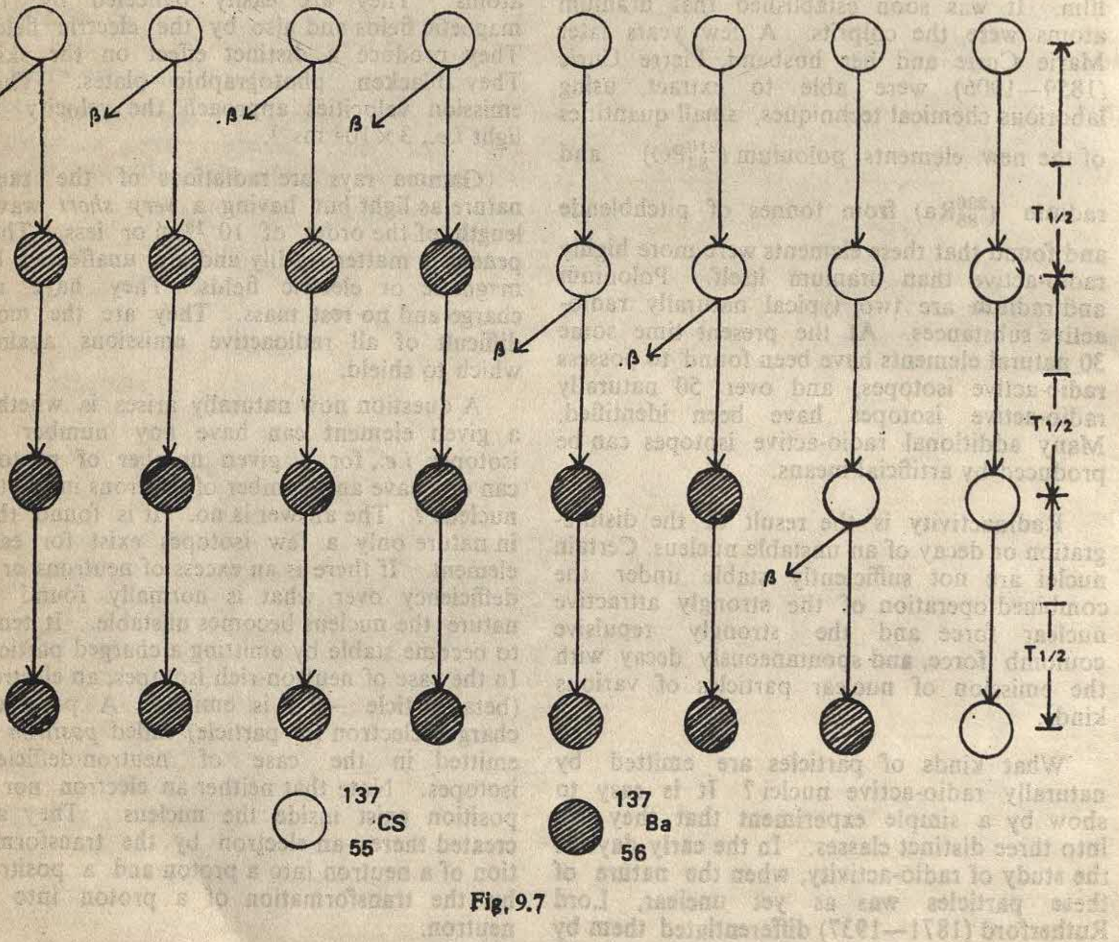

Fig. 9.7

5730 years and that of $^{24}_{11}\text{Na}$ is about 15 hours.

The half-life of $^{41}_{21}\text{Sc}$ is 0·6 s.

The half-life is a measure of the stability of a particular nuclear species. In one half-life the amount of the radio-active substance is cut in half; in two half-lives it is reduced by a factor of 4; in three half-lives by a factor of 8, and so on, as shown in Fig. 9.7 for the decay of $^{137}_{55}\text{Cs}$. At the end of three half-lives (*i.e.*, about 90 years in this case) seven out of every eight Cs nuclei have been changed into Ba, on the average. This kind of decay is plotted in Fig. 9.8, where the symbol $T_{1/2}$ denotes half-life.

9.7. NUCLEAR REACTIONS

We have been discussing natural radio-activity, a phenomenon caused by the intrinsic instability of some nuclei which leads to their emitting alpha, beta, or gamma particles and decaying into other kinds of nuclei. It is possible, however, to take extremely stable nuclei, such as $^{14}_{7}\text{N}$, the nuclei of the atoms forming nitrogen molecules in the air and make them unstable by bombarding them with highly energetic particles like protons, deuterons, or alpha particles. These particles can force their way inside a stable nucleus and create a new, unstable nucleus, which then decays into yet another nucleus and other smaller particles. This process is called a **nuclear reaction** or a **transmutation** or **artificial** (or **induced**) **rodio-activity**.

Suppose we fire high-energy alpha particles at a nitrogen nucleus. One reaction which occurs is found by experiment to be :

$$^{4}_{2}\text{He} + ^{14}_{7}\text{N} \rightarrow \left[\,^{18}_{9}\text{F}\,\right] \rightarrow ^{1}_{1}\text{H} + ^{17}_{8}\text{O}$$

In this reaction the alpha particle combines with the nitrogen nucleus to produce the highly unstable fluorine nucleus $^{18}_{9}\text{F}$, which then spontaneously decays into a rare isotope of oxygen and a proton as shown in Fig. 9.9. The braces around the $^{18}_{9}\text{F}$ indicate that this *compound* nucleus cannot be observed because its life-time is so short, but, to make sense of the experimental data, must be presumed to have existed for a very fraction of a second.

In fact the above mentioned nuclear reaction was the first to be achieved by Rutherford in 1919. Scientists encouraged by this first success showed that such nuclear reactions using α-particles could only be brought in light elements. For elements higher up in the

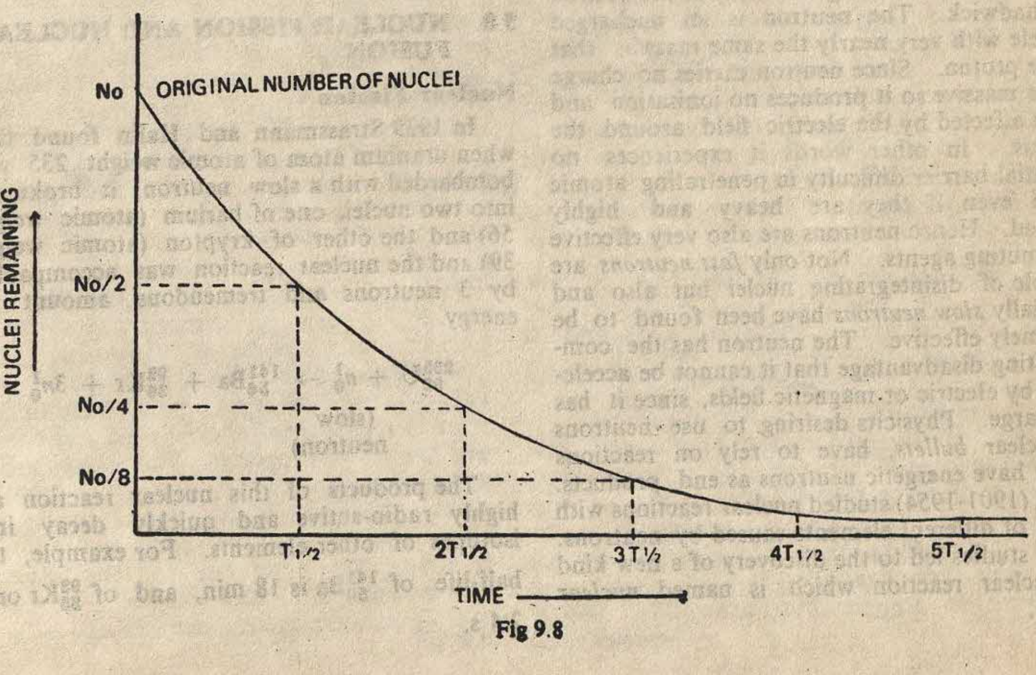

Fig 9.8

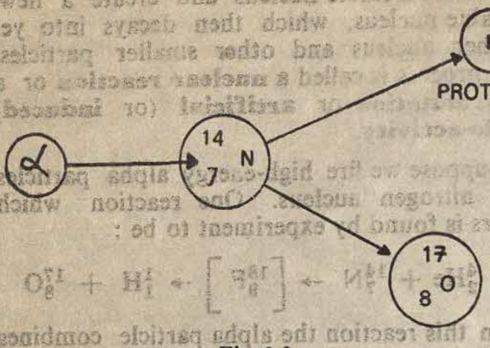

Fig. 9.9

periodic table, the coulomb repulsion between the atom's nucleus and the α-particle would be very large and the energy of the α-particle would not be enough to overcome this. To study this type of nuclear reactions in heavier elements, particle accelerators like *cyclotrons* and *betatrons* have been built. These can accelerate not only α-particles but also other charged particles *e.g.*, protons, deuterons and electrons to very high energies to get close enough to the bombarded nucleus to produce a new, unstable nucleus. These high energy charged particle beams have been used to study many nuclear reactions.

The real impetus to the nuclear reaction was given by the pioneering discovery of the *neutron* by Chadwick. The neutron is an uncharged particle with very nearly the same mass as that of the proton. Since neutron carries no charge and is massive so it produces no ionisation and is not affected by the electric field around the nucleus. In other words it experiences no potential barrier difficulty in penetrating atomic nuclei even if they are heavy and highly charged. Hence neutrons are also very effective transmuting agents. Not only *fast neutrons* are capable of disintegrating nuclei but also and especially *slow neutrons* have been found to be extremely effective. The neutron has the compensating disadvantage that it cannot be accelerated by electric or magnetic fields, since it has no charge. Physicits desiring to use neutrons as nuclear *bullets*, have to rely on reactions which have energetic neutrons as end products. Fermi (1901-1954) studied nuclear reactions with nuclei of different elements caused by neutrons. These studies led to the discovery of a new kind of nuclear reaction which is named *nuclear fission*.

Other examples of nuclear reactions

(*i*) ${}^{7}_{3}\mathrm{Li} + {}^{1}_{1}\mathrm{H} \rightarrow 2\,{}^{4}_{2}\mathrm{He} + \text{Energy}$

(*ii*) ${}^{2}_{1}\mathrm{H} + {}^{238}_{92}\mathrm{U} \rightarrow \left[{}^{240}_{93}\mathrm{N}_{p}\right] \rightarrow {}^{238}_{93}\mathrm{N}_{p} + 2n^{1}_{0}$

(neutron)

Equations Governing Nuclear Reactions

In the radioactive decay of nuclei, all the basic conservation principles of physics must be obeyed. These include the conservation of electric charge, of mass, of energy, and of linear and angular momentum.

To guarantee the conservation of electric charge and of mass (neglecting for the present the conversion of mass into energy) in any nuclear reaction, the following rules must be satisfied in the equation describing the reaction.

1. The sum of the charge numbers on the left side of the equation must be equal to the sum of the charge numbers on the right side of the equation. This guarantees the conservation of charge.

2. The sum of the mass numbers on the left side of the equation must be equal to the sum of the mass numbers on the right side of the equation. This guarantees the conservation of the number of nucleons taking part in the reaction, or the conservation of *nucleon number*.

9.8. NUCLEAR FISSION AND NUCLEAR FUSION

Nuclear Fission

In 1939 Strassmann and Hahn found that when uranium atom of atomic weight 235 was bombarded with a slow neutron, it broke up into two nuclei, one of barium (atomic weight 56) and the other of krypton (atomic weight 39) and the nuclear reaction was accompanied by 3 neutrons and tremendous amount of energy.

$${}^{235}_{92}\mathrm{U} + \underset{\substack{\text{(slow}\\\text{neutron)}}}{n^{1}_{0}} \rightarrow {}^{141}_{56}\mathrm{Ba} + {}^{92}_{36}\mathrm{Kr} + 3n^{1}_{0}$$

The products of this nuclear reaction are highly radio-active and quickly decay into isotopes of other elements. For example, the half-life of ${}^{141}_{56}\mathrm{Ba}$ is 18 min, and of ${}^{92}_{36}\mathrm{Kr}$ only 2·4 s.

Physicists all over the world took up these ideas and soon showed in their laboratories that not only does the above reaction occur, but other reactions like the above one also occur. All these reactions conserve charge and nucleon number, and all result in two isotopes each of which has roughly half the mass of the original uranium nucleus. All such nuclear reactions are examples of what is now called **nuclear fission**.

Thus nuclear fission is the breaking up of a heavy nucleus like uranium into two nuclei of intermediate masses, together with the release of two or more neutrons and large amounts of energy.

This definition points up two other important facts about fission. First, large amounts of energy are released in each such fission reaction, mostly in the form of the kinetic energies of the two heavy fission products and the neutrons. For example if 1 g of $^{235}_{92}U$ were to fission, the energy released would be about 10^7 joule. We would have to burn about 4 tonnes of coal to get the same amount of energy. Second, for each neutron absorbed, at least two or three neutrons are produced in the fission process. These two facts immediately led to the startling conclusion that the fission of uranium might provide a tremendous source of energy which could be used for either the well-being or the destruction of humanity.

The key to releasing the tremendous store of energy in a $^{235}_{92}U$ nucleus is a *chain reaction* of the kind shown in Fig. 9.10. A single neutron causes the fission of a $^{235}_{92}U$ nucleus into barium and krypton. In the fission reaction shown three neutrons are produced. Even if one of these escapes from the reaction region, two are left to produce additional fission reactions. Each of these new fission processes produces enough neutrons to cause two additional fission processes and so on. The energy thus released increases *exponentially*, since the number of fission reactions doubles at each

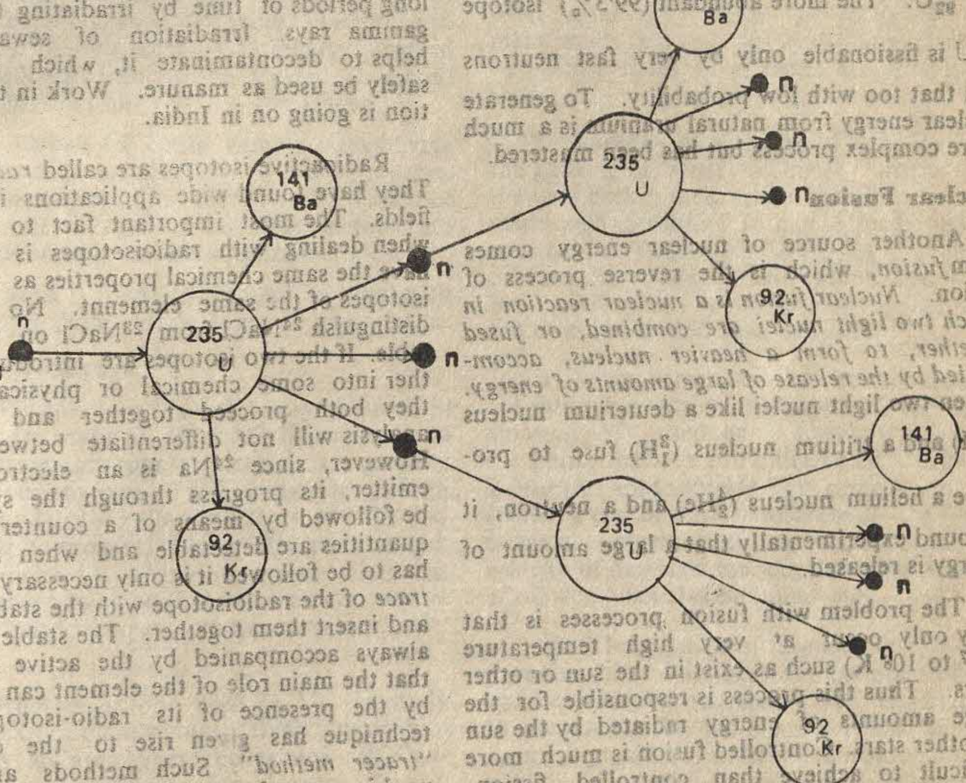

Fig. 9.10. Chain reaction.

stage of the chain. The result of this chain reaction is the release of a huge amount of energy in a very short time. This is the principle of an atom bomb. The first atom bomb used in Hiroshima utilized $^{235}_{92}U$ as the main reacting substance and the second atom bomb used in Nagasaki made use of plutonium $^{239}_{94}Pu$. The fission in both cases is similar and *uncontrolled.*

Now-a-days we can convert atomic energy (or nuclear energy) into mechanical power for industrial and other peaceful uses by possible methods, *viz., by controlling the chain reaction* by using a moderator *e.g.*, heavy water, deuterium, beryllium, carbon etc. An apparatus designed to use atomic energy in controlled form is called an *atomic (or nuclear) reactor* or *an atomic pile.* In India, we have power plants based on nuclear energy at Tarapore (Maharashtra), Kalpakkam (Tamilnadu) and Kota (Rajasthan). Any amount of natural uranium will not sustain a chain reaction. This is because natural uranium contains only 0·7% of $^{235}_{92}U$. The more abundant (99·3%) isotope $^{238}_{92}U$ is fissionable only by very fast neutrons and that too with low probability. To generate nuclear energy from natural uranium is a much more complex process but has been mastered.

Nuclear Fusion

Another source of nuclear energy comes from *fusion*, which is the reverse process of fission. *Nuclear fusion is a nuclear reaction in which two light nuclei are combined, or fused together, to form a heavier nucleus, accompanied by the release of large amounts of energy.* When two light nuclei like a deuterium nucleus ($^{2}_{1}H$) and a tritium nucleus ($^{3}_{1}H$) fuse to produce a helium nucleus ($^{4}_{2}He$) and a neutron, it is found experimentally that a large amount of energy is released.

The problem with fusion processes is that they only occur at very high temperature (10^7 to 10^8 K) such as exist in the sun or other stars. Thus this process is responsible for the large amounts of energy radiated by the sun or other stars. Controlled fusion is much more difficult to achieve than controlled fission. Though fusion reaction has been produced in the laboratory, we are still far from using this reaction as a source of continuous power.

9.9. USES OF RADIATIONS AND RADIOISOTOPES :

Researches in the field of nuclear energy have led to wide applications of nuclear radiations and radio-active isotopes in such diverse fields as medicine, engineering, agriculture, besides basic sciences.

Nuclear radiations are being used in the treatment of cancer and other tumours. These are also used to sterilize medical supplies, like syringes, blood transfusion sets etc. These are sterilized after packaging so that problems of recontamination during packaging are avoided. Radiations are also used to preserve wooden objects of art, like statues. Radiation exposure to plastic and rubber objects makes them suitable for high temperature use. Another important area of application of nuclear radiation is in the preservation of food. Potatoes and other food items can be preserved over long periods of time by irradiating them with gamma rays. Irradiation of sewage waste helps to decontaminate it, which can then safely be used as manure. Work in this direction is going on in India.

Radioactive isotopes are called *radiosotopes.* They have found wide applications in various fields. The most important fact to remember when dealing with radioisotopes is that they have the same chemical properties as the stable isotopes of the same elemennt. No one can distinguish $^{24}NaCl$ from $^{23}NaCl$ on the dinner table. If the two isotopes are introduced together into some chemical or physical system, they both proceed together and chemical analysis will not differentiate between them. However, since ^{24}Na is an electron (Beta) emitter, its progress through the system can be followed by means of a counter. Minute quantities are detectable and when a process has to be followed it is only necessary to mix a *trace* of the radioisotope with the stable isotope and insert them together. The stable isotope is always accompanied by the active isotope so that the main role of the element can be traced by the presence of its radio-isotope. This technique has given rise to the expression "*tracer method*". Such methods are widely used in research and industry, in agriculture, in biology and medicine, in metallurgy and engineering. Radioisotopes are used in diagnostic medicine and subsequent treatment in radiography and in the measurement of thickness and height and in leak detection in under-ground pipes containing liquids (usually petroleum oils) or gases. A few examples will now be described.

[*a*] **In Medicine** :

(*i*) Used as soluble ($^{24}NaCl$), this radioisotope finds many applications in the study of the transfer of soduim within the human body and provides valuable information concerning the flow dynamics of the body. If radio-sodium is injected at one extremity of the body it can be detected within a few seconds at the other extremity. The flow of blood can thus be followed and any constrictions on blood vessels are readily detected. Because of its comparatively short half-life the radio-sodium is soon transformed into stable magnesium.

(*ii*) Radio-iodine (^{131}I) has a half-life of eight days and is useful in medicine because it is known to accumulate in the thyroid gland and in the brain. Being a gamma emitter radio-iodine is useful in locating deep-seated disorders such as *brain tumours* and *malignant thyroid tumours* Ordinary thyroid iodine deficiency can also be treated in a controlled manner using (^{131}I) as the tracer.

(*iii*) Cobalt-60 emits gamma rays having an energy of about 2×10^{-13} J. Such penetraing gamma rays can be used in the treatment of *deep cancerous growth* and this method has largely *superseded* the old radium methods.

Leukemia is found to respond to treatment by radiation from radioisotopes of phosphorus.

[*b*] **In Agriculture** :

(*i*) Phosphorous is a necessary element in the complex make up of any fertilizer and the phosphorous (phosphate) uptake by growing plants from any type of soil or manure can be studied by labelling the fertilizer with P^{32} and following its progress through the root system to the foliage by means of a counter. It has been possible to show that some plants require root feeding whereas others require folia-feeding.

(*ii*) Another isotope used is ^{14}C to study the kinetics of plant photosynthesis. By growing plants in an atmosphere containing $^{14}CO_2$ it has been possible to understand more thoroughly the complicated bio-chemical reactions involved.

(*iii*) *Crop mutations* : Plant genetic studies have helped in obtaining crops with high yield, resistance to disease and adaptability to new environment. Desirable mutations are induced by irradiation of seeds by gamma rays or neutrons. High quality wheat and rice mutants resistant to certain diseases and several jute mutants have been evolved by this process.

Certain insect pests can be controlled by adopting the so called sterile male technique. The procedure consists of laboratory breeding of large number of male insects, sterilizing them with alpha-radiation and releasing them for mating in the infested area. This will bring about rapid reduction in the population of the insects

[*c*] **In Industry** :

(*i*) Penetrating gamma rays emitted by cobalt-60 can be used in the radiography of industrial weldings, in which they reveal faults much further inside the metal than would be possible with a 200 kilovolt X-ray set. Moreover, since the source is relatively small, many welds can be inspected simultaneously by placing them in a circle around a gamma source.

Yet another application of this isotope is the gauging of sheet thickness, where using the feed back principle, the machinery can be made self-adjusting. It can also be used to control the height of filling in packets of commercial powders. Low attenuation of the beam corresponds to an empty packet which can then be rejected automatically.

(*ii*) When petroleum products are transported through a single long pipeline ; radioactive antimony-124 used as a tracer is injected at the source between two different oil stocks and a detector kept outside the pipeline at the receiving end of the line announces the arrival of the new stock of oil. In a similar way the velocity of flow and the degree of intermixing of oil stock can also be found out.

(*iii*) The purpose of lubricant is to minimize the wear of surfaces, for example of gears and bearings, in machinery. It is necessary to select a suitable lubricant for this purpose. A small quantity of radioactive isotope of iron may be incorporated in the steel of a bearing under test. The lubricating oil is drawn and checked periodically for radioactivity caused by the wearing away of the steel bearing. This gives an idea of the effectiveness of the lubricant.

(*iv*) Radio-tracer techniques have been developed for the study of movement of silt on the sea-bed. In hydrology radio-tracers have been used for studying seepage in dams.

[*d*] **Carbon dating** :

It is recently developed technique to know the approximate age of certain items of animals or vegetable origin. Radio-isotope Carbon-14 is being continuously produced in the atmosphere by the action of cosmic rays and, at the sametime, is diminishing by disintegration. Thus there is a radioactive equilibrium for ^{14}C in the atmosphere the half-life of ^{14}C is 5600 years.

Animals and plants have also a certain amount of carbon-14 in them which remains in equilibrium with that in the atmosphere. After the death of an animal, carbon-14 in its body goes on disintegrating exponentially without this loss being made up. For example, old bones contain less carbon-14 than new bones and old wood contains less carban-14 than new wood. If we measure the ratio of ^{14}C to ^{12}C in the remanants of a dead organism and compare it with that in a living organism, it is possible to find when the organism ceased to exist. This method is now widely used by anthropologists and archaeologists and even historians for finding the age of ancient excavations, manuscripts etc. This method has become a standard technique and is known as *radioactive dating*.

The subject of radiations and radioisotopes and their applications is now so vast that the reader must refer to specific books for further information. Millions of rupees are are saved annually all over the world by their use and great progress has been made in medical diagnosis and treatment. It is probable that we shall benefit even more in the future by the applications of radiations and radioisotopes in factory and hospital.

SOLVED EXAMPLES

Example 1.

The radius of an atom is 10^{-10}m and that of the nucleus is 2×10^{-15}m, and that of the nucleus is 2×10^{-15} m. If the atom were magnified the size of the earth, *i.e*, a radius of 6400 km, what would be the size of the nucleus ?

Solution.

Radius of the atom in the first case $=10^{-10}$m

Corresponding radius of the nucleus

$=2\times10^{-15}$ m

Radius of the atom in the second case

$=6400$ km (when magnified)

$=64\ 0\times10^{3}$ m $=64\times10^{5}$ m

Let the radius of the nucleusin the second case $=x$

Since, radius of the nucleus is directly proportional to the radius of the atom, so we have

$$\frac{x}{2\times10^{-15}}=\frac{64\times10^{5}}{10^{-10}}$$

or $$x=\frac{64\times10^{5}\times2\times10^{-15}}{10^{-10}}$$

$$=\mathbf{128\ m}$$

Example 2

The radii, r_A of most nuclei, can be represented by the formula

$$r_A=1\times10^{-15}\,A^{1/3}$$

where A is the mass number. Determine r_A for $A=1$, 2, 8, 27, 64, 125 and plot r_A as a function of A.

Solution.

$$r_A=1\times10^{-15}\,A^{1/3}$$

(*i*) When $A=1$

$$r_A=1\times10^{-15}\,(1)^{1/3}$$

$$=\mathbf{1\times10^{-15}\ m}$$

(*ii*) When $A=2$

$$r_A=1\times10^{-15}\,(2)^{1/3}$$

$$=\mathbf{1{\cdot}26\times10^{-15}\ m}$$

(*iii*) When $A=8$

$$r_A=1\times10^{-15}(8)^{1/3}$$

$$=1\times10^{-15}\,(2^3)^{1/3}$$

$$=\mathbf{2\times10^{-15}\ m}$$

(*iv*) When $A=27$

$$r_A=1\times10^{-15}(3^3)^{1/3}$$

$$=\mathbf{3\times10\ ^{15}\ m}$$

(*v*) When $A=64$

$$r_A=1\times10^{-15}\,(4^3)^{1/3}$$

$$=\mathbf{4\times10^{-15}\ m}$$

(*vi*) When $A=125$

$$r_A=1\times10^{-15}(5^3)^{1/3}$$

$$=\mathbf{5\times10^{-15}}$$

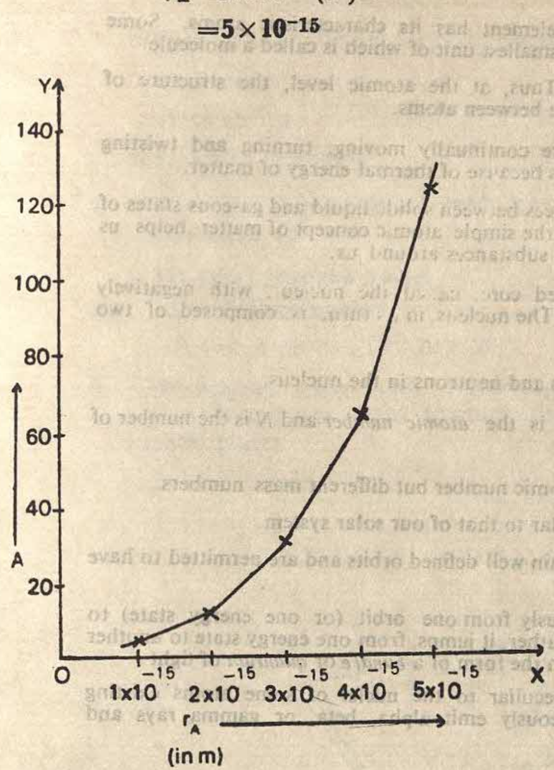

Fig. 9.11

Example 3.

How many protons and neutrons are there in germanium ${}^{72}_{32}Ge$?

Solution.

We know that

$$A=Z+N$$

where A=mass number

Z=atomic number *i.e.*, number of protons or electrons

N=number of neutrons.

Since ${}^{A}_{Z}X={}^{72}_{32}Ge$

$\therefore$ number of protons$=Z=32$

Hence, number of neutrons$=N=A-Z$

$$=72-32$$

$$=40$$

Thus ${}^{72}_{32}Ge$ has 32 protons and 40 neutrons.

Example 4.

Identify the unknown particle involved in the following nuclear reaction.

$${}^{137}_{55}Cs \longrightarrow {}^{0}_{-1}e \quad + \quad {}^{A}_{Z}X$$

(Beta) particle   (unknown particle)

where the unknown nucleus ${}^{A}_{Z}X$ is to be determined

Solution.

From the *conservation-of-charge principle* we have $55=Z-1$ or $Z=56$. Similarly from the *principle of conservation of nucleon number*, we have $137=A+0$, or $A=137$. The unknown nucleus is therefore ${}^{137}_{56}X$. From the periodic table the element with atomic number 56 is seen to be barium. Hence the unknown particle is

$$\boxed{{}^{137}_{56}Ba}$$

Example 5.

A sample of kr gas contains $2{\cdot}00\times10^{20}$ atoms of ${}^{88}_{36}Kr$ at a time $t=0$. The half-life of ${}^{88}_{38}Kr$ is $2{\cdot}8h$ At a time $t=11{\cdot}2\ h$ later, how many ${}^{88}_{36}Kr$ atoms remain ?

Solution.

In one half-life, the amount of the radioactive substance is cut in half ; in two half-lives it is reduced by a factor of 4, in half-lives by a factor of 8 and in four half-lives by a factor of 16 and so on.

Thus in four half-lives ($11{\cdot}2h$), the number of ${}^{88}_{36}Kr$ atoms decreases by a factor of $2^4=16$ Hence the number of atoms present after $11{\cdot}2\ h$

$$=\frac{2{\cdot}00\times10^{20}}{16}$$

$$=\mathbf{1{\cdot}25\times10^{19}\ atoms}$$

SUMMARY

1. All matter consists of a few elements. Each element has its characteristic atoms. Some elements can combine to form a compound, the smallest unit of which is called a molecule.

   Molecules are the *building blocks* of matter. Thus, at the atomic level, the structure of matter appears to be granular *i.e.* with free space between atoms.

2. Molecules are in constant motion. They are continually moving, turning and twisting around. This random motion of the molecule is because of thermal energy of matter.

3. On the basis of atomic theory, the main differences between solid, liquid and gaseous states of a substance can be illustrated. In other words, the simple atomic concept of matter helps us to understand the various physical properties of substances around us.

4. An atom consists of a central positively charged core, called the nucleus, with negatively charged electrons revolving round it in orbits. The nucleus, in its turn, is composed of two types of particles, protons and neutrons.

   Nucleus is the genetic name given to the protons and neutrons in the nucleus.

5. $A = Z + N$ where A is the mass number ; Z is the *atomic number* and N is the number of neutrons.

6. *Isotopes* are the nuclei which have the same atomic number but different mass numbers.

7. In some ways, the structure of an atom is similar to that of our solar system.

8. In an atom, electrons can move only in certain well defined orbits and are permitted to have only certain discrete energy values.

9. An electron in an atom cannot move continuously from one orbit (or one energy state) to another orbit (or another energy state). Rather, it jumps, from one energy state to another and in so doing it absorbs or releases energy in the form of a *bundle* or *quantum* of light

10. *Natural radio-activity* is the phenomenon peculiar to the nuclei of some atoms existing naturally on the earth in which they spontaneously emit alpha, beta, or gamma rays and change into other kinds of nuclei.

    Alpha (α) particles = helium nuclei $\left({}^{4}_{2}\text{He} \right)$

    Beta (β) particles = electrons $\left({}_{-1}^{0}\text{e} \right)$

    Gamma (γ) rays = high-energy particles.

11. *Half-life* ($T_{1/2}$) is the time required for half the nuclei in a sample of a particular nuclear species to decay radioactively.

12. One element can be changed into another artificially. This process is called a *nuclear reaction* or a *transmutation*.

13. Since neutron is an electrically neutral particle, it can penetrate the nucleus easily.

14. *Nuclear fission* is the breaking up of a heavy nucleus like uranium into two nuclei of intermediate masses, together with the release of two or more neutrons and large amounts of energy.

15. *Chain reaction* is the rapid build-up of energy which occurs in a nuclear bomb when the number of neutrons producing fission at successive stages of the reaction increases exponentially.

16. *Nuclear reactor* is a large boiler in which nuclear processes generate heat which is then converted in electricity by a steam-electric turbine.

17. *Nuclear fusion* is a nuclear reaction in which two light nuclei are combined, or *fused* together, to form a heavy nucleus, accompanied by the release of large amounts of energy.

18. *Nuclear radiation* is the radiation emitted in the radio-active decay of nuclei.

19. Radioactive isotopes are called radio-isotopes.

20. Nuclear radiations and radio-isotopes have wide applications in various fields--medicine agriculture ; industry ; carbon dating etc.

QUESTIONS

[A] Objective Type Questions :

1. Which of the following is (are) constituent particles of the nucleus of all atoms ?
   - (*i*) protons
   - (*ii*) electrons
   - (*iii*) alpha particles.

2. The alpha particle emitted from within the nucleus of a radioactive source equivalent to
   - (*i*) two hydrogen nuclei
   - (*ii*) a helium nucleus
   - (*iii*) two protons + two neutrons.

3. The diagram (Fig. 9.12) below represents a horizontal beam of beta rays travelling towards and just about to enter the region between two oppositely charged parallel metal plates.

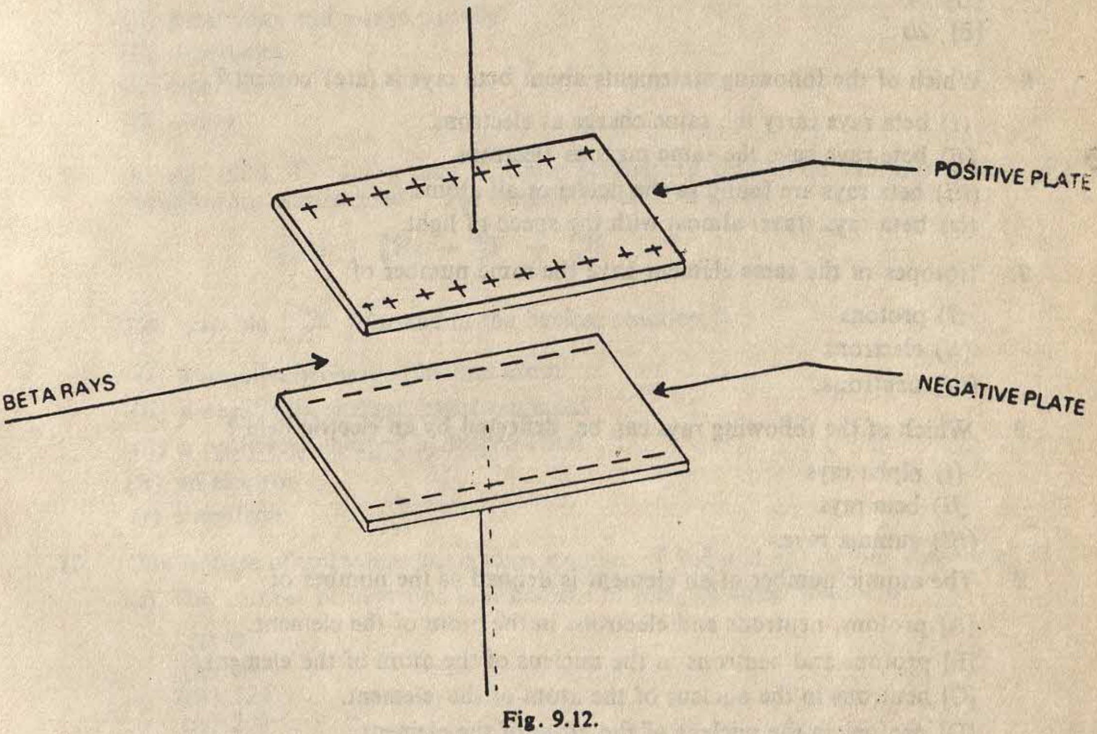

Fig. 9.12.

To an observer standing behind the source of the rays, the beta rays will be

[A] undeflected and will continue to move in a straight line.

[B] deflected vertically upwards towards the positive plate.

[C] deflected vertically downwards towards the negative plate.

[D] deflected in a horizontal plane towards the right.

[E] deflected in a horizontal plane towards the left.

4. This question is concerned with the following items :

[A] proton [B] neutron [C] alpha particle [D] ion [E] electron.

Choose the item most closely related to each of the following :

- (*i*) a charged particle in the nucleus of all atoms. Its charge is equal and opposite to that of the electron.
- (*ii*) a negatively charged particle.
- (*iii*) an uncharged particle found in most atoms.
- (*iv*) a particle produced by the removal of one or more electrons from a neutral atom
- (*v*) a particle with a mass approximately four times that of the hydrogen atom.

5. At 12 noon on Sunday the corrected count-rate for a radio-active source is 240 counts per second. At 12 noon on Tuesday the count-rate falls to 120 counts per second. At 12 noon on Saturday the count-rate, in counts per second, will be

[A] 60
[B] 40
[C] 30
[D] 24
[E] 20

9. Which of the following statements about beta rays is (are) correct ?

- (*i*) beta rays carry the same charge as electrons.
- (*ii*) beta rays have the same mass as electrons.
- (*iii*) beta rays are found in the nuclei of all atoms.
- (*iv*) beta rays travel almost with the speed of light.

7. Isotopes of the same element have the same number of

- (*i*) protons
- (*ii*) electrons
- (*iii*) neutrons.

8. Which of the following rays can be deflected by an electric field ?

- (*i*) alpha rays
- (*ii*) beta rays
- (*iii*) gamma rays.

9. The atomic number of an element is defined as the number of

[A] protons, neutrons and electrons in the atom of the element.
[B] protons and neutrons in the nucleus of the atom of the element.
[C] neutrons in the nucleus of the atom of the element.
[D] protons in the nucleus of the atom of the element.
[E] electrons in the atom of the element.

10. A radio-active atom emits an alpha particle. Which of the following statements is (are) true ?

- (*i*) the mass number of the atom decreases by 4.
- (*ii*) the atomic number of the atom decreases by 2.
- (*iii*) the weight of the atom decreases by 6 units,

11. A certain radioactive substance is a beta particle emitter. This means that the nuclei of some of the atoms disintegrate and produce :

[A] helium nuclei

[B] high speed electrons

[C] electromagnetic waves

[D] protons

[E] neutrons

12. Particles which can be added to be the nucleus of an atom without changing its chemical properties are called :

(*i*) electrons

(*ii*) protons

(*iii*) neutrons

(*iv*) alpha particles

(*v*) molecules

13. Radio-active substances give out three types of emissions, α-particles, β-particles and γ-rays. Of these, the most penetrating are :

[A] α-particles and β-particles equally

[B] β-particles and γ-rays equally

[C] α-particles

[D] β-particles

[E] γ-rays

14. About 1930, F. Joliot and I. Curie bombarded aluminium with α-particles. Radio-phosphorous was formed. The nuclear reaction is given

$${}^{27}_{18}\text{Al} + {}^{3}_{2}\text{He} \rightarrow {}^{30}_{15}\text{P} + {}^{A}_{Z}\text{X}$$

The particle $\left({}^{A}_{Z}\text{X}\right)$ formed in the nuclear reaction is :

(*i*) a negatively charged helium atom

(*ii*) a negatively charged hydrogen atom

(*iii*) a positively charged hydrogen atom

(*iv*) an electron

(*v*) a neutron

15. One isotope of polonium has a mass number of 208 and an atomic number of 84.

(*a*) The number of neutrons in a nucleus of this polonium isotope is

(*i*) 0
(*ii*) 84
(*iii*) 124
(*iv*) 208
(*v*) 292

(*b*) The number of orbital electrons in a neutral atom of this polonium isotope is

(*i*) 0
(*ii*) 84
(*iii*) 124
(*iv*) 208
(*v*) 292

(*c*) The number of protons in the nuclei of the different polonium isotopes is

- (*i*) 84
- (*ii*) 124
- (*iii*) 208
- (*iv*) 292
- (*v*) variable

16. When a mixed beam of α-particles, β-particles and γ-rays enters a magnetic field

- [A] all three radiations are undeviated.
- [B] all three radiations are deviated.
- [C] the γ-rays are undeviated while the α and β-particles are deviated in the same direction.
- [D] the γ-rays are undeviated while α and β-particles are deviated in opposite directions.

17. An isotope is said to have a half-life of 8 years. This means that

- [A] after 1 year, 1/8 of the isotope has decayed.
- [B] after 1 year, 1/8 of the isotope remains.
- [C] after 4 years, 1/4 of the isotope has decayed.
- [D] after 16 years, 1/4 of the isotope remains.
- [E] after 16 years the isotope has completely decayed.

19. When $^{9}_{4}\text{Be}$ is bombarded with α-particles, one of the products is $^{12}_{6}\text{C}$. The other is

- (*i*) an electron
- (*ii*) a deuteron
- (*iii*) a proton
- (*iv*) a neutron

19. When a stream of particles falls on $^{10}_{5}\text{B}$ it is strongly absorbed and $^{7}_{3}\text{Li}$ and alpha particles are produced. The bombarding particles are

- [A] charged
- [B] nuclei of an element with low atomic number.
- [C] a penetrating radiation with zero rest mass.
- [D] neutral with mass similar to that of electrons.
- [E] neutral with mass similar to that of protons.

20. $^{235}_{92}\text{U}$ nucleus differs from $^{238}_{92}\text{U}$ nucleus in that the latter contains

- (*i*) 3 more protons
- (*ii*) 3 more neutrons
- (*iii*) 3 more electrons
- (*iv*) 3 more alpha particles

(B) Very Short Answer Type Questions :

1. What is the approximate diameter of a hydrogen atom ?

2. What is the structure of matter at the atomic level ?

3. What are the building blocks of matter ?
4. Are molecules of matter stationary ?
5. What is the charge of an electron ?
6. What is the mass of an electron ?
7. What is the charge of a proton ?
8. What is the mass of a proton ?
9. What is the charge of a neutron ?
10. What is the mass of a neutron ?
11. What is mass number ?
12. What is atomic (or charge) number ?
13. What are isotopes ?
14. Give two examples of isotopes.
15. What happens when an electron in an atom jumps from a higher energy state to a lower energy state ?
16. What is the approximate size of a nucleus ?
17. What is a deuterium ?
18. What is heavy water ?
19. What is the molecular weight of heavy water D_2O ?
20. What is an alpha particle ?
21. What is a beta (β) particle ?
22. What is a positron ?
23. What are gamma rays ?
24. Do electrons and positrons exist inside the nucleus ?
25. What is the charge of gamma rays ?
26. Name the places in India where the power plants based on nuclear energy are situated.
27. Name the process which goes on inside the sun (or a star) which is responsible for the large amount of energy radiated by it.
28. Name the process which is responsible for the large amount of nuclear energy when $^{235}_{92}U$ is bombarded by low energy neutrons
29. If 1 g of $^{235}_{92}U$ were to fission, approximately how much energy in joules would be released ?
30. What are particle accelerators ?
31. What are radio-isotopes ?

(C) Short Answer Type and Essay-type Questions :

1. Explain briefly the difference between solid, liquid and gaseous states on the basis of atomic theory.

2. Sketch a model of an atom and name the different parts. How is light emitted by atoms ?

3. What is an electron ? Mention some of its properties.

4. Comment on the statement that molecules are the building blocks of matter.

5. What are

   (*i*) nuclear radiations and (*ii*) radioisotopes ?

   Mention some of their applications in diverse fields as medicine ; engineering, agriculture and basic sciences.

6. (*a*) What is natural radioactivity ?

   (*b*) What are radioactive substances ? Name three radioactive substances.

   (*c*) What is the cause of radioactivity ?

7. What are

   (*a*) alpha rays (*b*) beta rays and (*c*) gamma rays ?

   Mention three properties of each.

8. What is the definition of the following terms ?

   (*i*) nucleon (*ii*) mass number (*iii*) atomic number (*iv*) isotopes.

9. What is a nuclear reaction ? What is another name for it ? Give one example of a nuclear reaction.

10. When an alpha particle is emitted from a nucleus, how are mass number and atomic number affected ?

11. What are the mass numbers of (*i*) the neutron and (*ii*) the electron ?

12. What is gamma radiation ? What is its wave-length ?

13. What is meant by the half-life of an isotope ?

14. What makes neutrons such good particles for bombarding nuclei ?

15. What is the difference between a nuclear fission and a nuclear fusion ?

16. What is a chain reaction ? Distinguish between a controlled chain reaction and an uncontrol chain reaction.

17. How many neutrons are there in the nucleus of ${}^{39}_{19}K$? How many protons ? How many electrons does this atom have ?

18. Why do chemists consider different isotopes to be the same element even though their nuclei are not the same ?

19. Would the optical spectra (or light emitted) of ${}^{35}Cl$ and ${}^{37}Cl$ atoms differ in any major way ?

20. Why is the nuclear fusion reaction so much more difficult to initiate than the nuclear fission reaction ?

21. Sketch and label energy levels of hydrogen atom.

22. Compare structure of an atom with our solar system.

23. Under what condition a nucleus becomes unstable ? When are β^+ and β^- particles emitted ? [*A.I.S.S. 1987*)

    [**Hints** : For neutron deficient →β^+. For neutron rich →β^-]

24. Give one practical application each for :

    (*i*) Nuclear fission (*ii*) Radio-isotope. [*A.I.S.S. 1987*]

PROBLEMS

1. Radius of a nucleus is given by $(1{\cdot}2\times10^{-15}\text{ m})(A)^{1/3}$. Compare the size of a uranium nucleus ($^{238}_{92}$U) with that of a hydrogen nucleus ($^{1}_{1}$H). [**Ans.** 6·2]

2. The radius of an atom is 10^{-10} m and that of the nucleus is $1{\cdot}2\times10^{-15}$ m. If the atom were magnified to a radius of 1000 Km, what would be the size of the nucleus ? [**Ans.** 12 m]

3. How many protons and neutrons are there in

   (*i*) $^{207}_{82}$Pb (*ii*) $^{137}_{56}$Ba (*iii*) $^{238}_{92}$U ? [*A.I.S.S. 1987*]

   [**Ans.** (*i*) 82 ; 125 (*ii*) 56 ; 81 (*iii*) 92 ; 146]

4. Identify the unknown particle involved in the following nuclear reaction.

$$^{2}_{1}\text{H} + ^{3}_{1}\text{H} \rightarrow\ ^{A}_{Z}\text{X} + ^{1}_{0}n$$

[**Ans.** $^{4}_{2}$He]

5. A sample of $^{60}_{27}$CO contains $1{\cdot}0\times10^{19}$ atoms at a time $t=0$. At a time $t=20{\cdot}96$ years later, how many $^{60}_{27}$CO atoms remain ? Half-life of $^{60}_{27}$CO is 5·24 years.

   [**Ans.** $6{\cdot}25\times10^{17}$]

6. The radii, r_A, of most nuclei, can be represented by the formula

$$r_A=(1{\cdot}2\times10^{-15}\text{ m})(A)^{1/3}$$

where A is the mass number. Determine r_A for $A=1$, 8, 27, 64, 125 and plot r_A as a function of A.

[**Ans.** $1{\cdot}2\times10^{-15}$ m ; $2{\cdot}4\times10^{-15}$ m ; $3{\cdot}6\times10^{-15}$ m ; $4{\cdot}8\times10^{-15}$ m ; $6{\cdot}0\times10^{-15}$ m]

7 Copy and complete the following table to show the number of protons, neutrons, and electrons in the given atoms

Isotope	*Mass number*	*Protons*	*Neutrons*	*Electrons*
$^{6}_{3}$Li				
$^{2}_{1}$H				
$^{4}_{2}$He				

8. The isotopes shown in the following table are all stable :

Isotope	$^{27}_{13}$Al	$^{56}_{26}$Fe	$^{93}_{41}$Nb	$^{127}_{53}$I	$^{159}_{65}$Tb	$^{197}_{79}$Au
Number of protons, *p*						
Number of neutrons, *n*						
$\frac{p}{n}$						

Complete the table and draw a graph of p/n against p.

APPENDIX 1

TRIGONOMETRIC FUNCTIONS

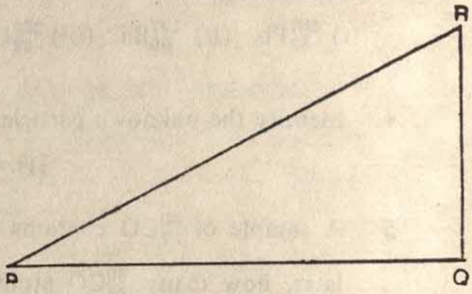

Fig. (*a*). Right-angled triangle PQR

Consider a right-angled triangle *PQR* (Fig. *a*). Let θ be the angle that the hypotenuse *PR* makes with the base *PQ*. We define the following trignometric functions :

(*i*) sin θ, abbreviated as sin θ :

$$\sin\theta = \frac{\text{perpendicular}}{\text{hypotenuse}} = \frac{QR}{PR}$$

(*ii*) cosine θ, abbreviated as cos θ :

$$\cos\theta = \frac{\text{base}}{\text{hypotenuse}} = \frac{PQ}{PR}$$

(*iii*) tangent θ, abbreviated as tan θ :

$$\tan\theta = \frac{\text{perpendicular}}{\text{base}} = \frac{QR}{PQ}$$

We further note that

$$\tan\theta = \frac{QR}{PQ} = \frac{QR}{PR} \cdot \frac{PR}{PQ} = \frac{\sin\theta}{\cos\theta}$$

Also, since for this right-angled triangle

$$(PQ)^2 + (QR)^2 = (PR)^2$$

We obtain on dividing both sides by $(PR)^2$

$$\left[\frac{PQ}{PR}\right]^2 + \left[\frac{QR}{PR}\right]^2 = 1$$

or

$$\cos^2\theta + \sin^2\theta = 1$$

Given the value of any of the ratios : $\frac{PQ}{PR}$ or $\frac{QR}{PQ}$ or $\frac{QR}{PR}$

We can find the angle θ from the table of trigonometric functions. Values of these functions for a few values of the angle are given below :

θ → Function ↓	0°	30°	45°	60°	90°
sin θ	0	$\frac{1}{2}$	$\frac{1}{\sqrt{2}}$	$\frac{\sqrt{3}}{2}$	1
cos θ	1	$\frac{\sqrt{3}}{2}$	$\frac{1}{\sqrt{2}}$	$\frac{1}{2}$	0
tan θ	0	$\frac{1}{\sqrt{3}}$	1	$\sqrt{3}$	∞

Note that $\sqrt{2}=1{\cdot}414$, $\sqrt{3}=1{\cdot}732$, $\frac{1}{\sqrt{2}}=0{\cdot}707$ and $\frac{1}{\sqrt{3}}=0{\cdot}577$

In the right angle triangle ABC, we extend the base AB to any length AB' and at B' draw a perpendicular parallel to BC. It will cut the line AC produced, at some point C' (Fig. *b*). We thus get a new right-angled triangle $AB'C'$. The bigger triangle $AB'C'$ is similar to the triangle ABC. By the property of similar triangles we know that

$$\frac{AB}{AB'}=\frac{AC}{AC'}=\frac{BC}{B'C'}$$

From these equalities, we get

$$\frac{BC}{AC}=\frac{B'C'}{AC'}\ ;\ \frac{AB}{AC}=\frac{AB'}{AC'}\ ;\ \frac{BC}{AB}=\frac{B'C'}{AB'}$$

From this, it follows that for a given angle θ, the ratios $\frac{BC}{AC}$, $\frac{AB}{AC}$ and $\frac{BC}{AB}$ and hence the functions $\sin\theta$, $\cos\theta$ and $\tan\theta$ are independent of the length of the base (AB) of the right-angled triangle.

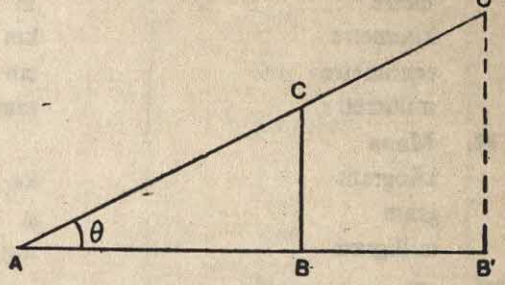

Fig. (*b*) Extension of sides of the triangle gives us a similar right-angled triangle.

APPENDIX 2

UNITS OF PHYSICAL QUANTITIES

Name	*Abbreviation*	*Remarks*
I. Length		
metre	m	standard
kilometre	km	$km=10^3$ m
centimetre	cm	$cm=10^{-2}$ m
millimetre	mm	$mm=10^{-3}$ m
II. Mass		
kilogram	kg	standard
gram	g	$g=10^{-3}$ kg
milligram	mg	$mg=10^{-6}$ kg
III. Time		
second	s	
minute	min	min=60 s
hour	h	h=3600 s
IV. Area		
square metre	m^2	
square centimetre	cm^2	$cm^2=10^{-4}\ m^2$
square millimetre	mm^2	$mm^2=10^{-6}\ m^2$
V. Volume		
cubic metre	m^3	
cubic centimetre	cm^3	$cm^3=10^{-6}\ m^3$
cubic millimetre	mm^3	$mm^3=10^{-9}\ m^3$
litre	l	$l=10^{-3}\ m^3$
VI. Density		
kilogram per metre cube	kg/m^3	
gram per cubic centimetre	g/cm^3	$g/cm^3=10^3\ kg/m^3$
VII. Velocity		
metre per second	m/s	
centimetre per second	cm/s	$cm/s=10^{-2}$ m/s
kilometre per hour	km/h	$km/h=\frac{1}{3{\cdot}6}$ m/s
VIII. Acceleration		
meter per second square	m/s^2	
centimetre per second square	cm/s^2	$cm/s^2=10^{-2}\ m/s^2$
IX. Angular velocity		
radians per second	(rad/s) ; $\frac{1}{s}$*	

*Since angle is measured as a ratio, the unit of angular velocity is usually taken as s^{-1}.

APPENDIX 3

THE GREEK ALPHABET

Symbol	*Pronunciation*	*Symbol*	*Pronunciation*
α	**Alpha**	ν	**Nu**
β	**Beta**	ξ	**Xi**
γ	**Gamma**	ο	**Omicron**
δ	**Delta**	π	**Pi**
ϵ	**Epsilon**	ρ	**Rho**
ζ	**Zeta**	σ	**Sigma**
η	**Eta**	τ	**Tau**
θ	**Theta**	υ	**Upsilon**
ι	**Lota**	ϕ	**Phi**
κ	**Kappa**	χ	**Chi**
λ	**Lambda**	ψ	**Psi**
μ	**Mu**	ω	**Omega**